# WIND AND SOLAR PROVE THE UNITED STATES DOES NOT NEED A BRIDGE FUEL: RENEWABLES ARE READY NOW

by
Stephanie Dresen

A capstone submitted to Johns Hopkins University in conformity with the requirements for the degree of Master of Science in Energy Policy and Climate

Baltimore, Maryland
December 2018

© 2018 Stephanie Dresen
All Rights Reserved

## ABSTRACT

This study set out to address whether nuclear energy would be a better bridge fuel than natural gas for the United States to address emissions reductions more quickly. However, this study also analyzed whether a bridge fuel was necessary at all, rather, were renewable energy sources readily deployable now. The study looked at eight different metrics of the energy sector across three energy sources: natural gas, nuclear energy, and renewables (combined onshore wind and utility solar photovoltaics). The eight metrics analyzed were broken down further into quantitative metrics: cost, implementation speed, and $CO_2$ emissions and qualitative metrics: public opinion, available capacity, environmental impact, reliability, and needed policy. A meta-analysis was performed and the data from which was used to evaluate the impact of each metric on each energy source. The impacts were normalized within each metric. Finally, a multi-criterion decision analysis tool was developed using the normalized data so that scientists, policymakers, academics, etc. may use it to determine the best-case-scenario energy source given different input weights of each metric. When all metrics are weighted/valued the same, nuclear energy does prove to be a better bridge fuel than natural gas. However, renewable energy performs even better, proving that the United States does not need a bridge fuel.



*Keywords: meta-analysis, multi-criterion decision analysis, natural gas, methane, nuclear energy, nuclear, solar, wind, renewables, renewable energy, cost, implementation speed, $CO_2$ emissions, carbon dioxide, greenhouse gas emissions, public opinion, available capacity, environmental impact, reliability, needed policy, bridge fuel, climate change*

## TABLE OF CONTENTS

## EXECUTIVE SUMMARY

Anthropogenic climate change is quickly becoming the largest threat to humanity as it exists today. Both the Intergovernmental Panel on Climate Change and the National Climate Assessment released reports in fall 2018 stating that rapid, overarching changes are needed both in the United States (U.S.) and around the world to combat climate change (Intergovernmental Panel on Climate Change, n.d.; U.S. Global Change Research Program 2018). Increased greenhouse gas emissions have been identified as the greatest contributor to global warming. In the U.S., the energy sector represents the largest source of emissions (U.S. Environmental Protection Agency 2018). It has been suggested that renewable energy is not yet ready to replace fossil fuels, but instead, that the U.S. should transition from high-emitting fossil fuel sources, like coal, to lower-emitting sources, like natural gas (Pierce Jr. 2012).

And yet, given the reports showing that the consequences of climate change are already bearing down, this study hypothesizes that a low-carbon energy source is needed immediately – and that nuclear energy would be a better bridge fuel to a renewable future than natural gas. This study looks at eight metrics impacting America's choice of energy sources: cost, implementation speed, $CO_2$ emissions, public opinion, available capacity, environmental impact, reliability, and policies needed to determine the best bridge fuel, and whether one is even necessary. Natural gas, nuclear energy, and renewables (here combined onshore wind and utility-scale solar photovoltaics) were analyzed and compared across each of these eight metrics.

A multi-criterion decision analysis tool was developed to compare the results of each of the eight metrics across each energy source. When all metrics are weighted with equal value, renewables score better than both natural gas and nuclear energy, illustrating that the U.S. does not, in fact, need a bridge fuel and that low-carbon renewables are readily deployable now.

## INTRODUCTION

Regardless of remaining speculation, consensus shows that, “97 percent or more of actively publishing climate scientists agree: climate-warming trends over the past century are extremely likely due to human activities,” (Shaftel 2018). Anthropogenic climate change is indeed happening, and greenhouse gas emissions are the primary cause (Shaftel 2018). In order to address this immense problem, scientists, policymakers, and academics alike have begun looking at a number of ways to reduce greenhouse gas emissions in America and around the world (U.S. Global Change Research Program 2018; Intergovernmental Panel on Climate Change, n.d.). According to the United States Environmental Protection Agency (EPA), “the largest source of greenhouse gas emissions from human activities in the United States is from burning fossil fuels for electricity, heat, and transportation,” (U.S. Environmental Protection Agency 2018). So, reducing the burning of fossil fuels for energy has the greatest potential for reducing greenhouse gas emissions and therefore mitigating the impact of climate change.

In order to do this, the United States (U.S.) has begun, albeit slowly and with much regional opposition, to retire old fossil-fuel-burning plants and replace them (U.S. Energy Information Administration 2018a). But this then begs the question, replace them with what? First, let it be clear that the U.S. is closing and replacing fossil-fuel-burning plants for a number of reasons including outdated technology, modern environmental standards, access to source material, and increasing automation, not solely to combat climate change (Tabuchi 2017). However, the issue remains. After a plant closes, for whatever reason, so long as demand has not drastically changed, the energy it produced still needs to be replaced. This then returns to the original question: replaced with what? While the ideal answer is an economical fuel source that produces no greenhouse gas emissions, the U.S. has struggled to transition from fossil fuels to carbon-free energy sources (U.S. Global Change Research Program 2018).

The transition is difficult for a variety of reasons. U.S. energy infrastructure was built around fossil-fuel energy sources and retrofitting the energy infrastructure of an entire country overnight just is not possible (Walton 2018). Additionally, regional opposition to the phase-out of fossil fuel sources, such as coal, has proven to be a complex situation both economically and politically, particularly in regions where coal is mined (Tabuchi 2017). However, some academics have suggested an alternative solution, the use of a bridge fuel. The concept of a bridge fuel is, that while the U.S. may not be able to transition to a carbon-free energy system immediately, replacing high-emitting sources, like coal, with lower emitting sources, like natural gas, will create a 'bridge' allowing the U.S. to slowly transition to a carbon-free energy sector (Rapier 2018).

Frequently, natural gas has been promoted as the bridge fuel of choice (Pierce Jr. 2012). It emits relatively less carbon dioxide ($CO_2$) than coal does for the equivalent energy unit. Additionally, the energy infrastructure in the U.S. is suited to natural gas, so in many regions it would be a drop-in ready fuel source (Rapier 2018). Over the last decade natural gas prices have dropped significantly due to new technologies such as hydraulic fracturing (fracking) and horizontal drilling, that have increased its available supply (Kerr 2010; Wang and Krupnick 2013). While these reasons make a good case for natural gas as a bridge fuel, it is worth considering whether implementing increased use of natural gas would reduce greenhouse gas emissions quickly enough to combat climate change. A special report titled, *Global Warming of 1.5 °C*, was released by the Intergovernmental Panel on Climate Change (IPCC) in October 2018. In it, climate scientists from around the world reported, "on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways," (Intergovernmental Panel on Climate Change, n.d.). According to the report, anthropogenic climate change has already increased the average global temperature by 1.0 °C and without, "rapid, far-reaching and unprecedented changes in all aspects of society" the world is unlikely to limit the increase to only 1.5 °C above pre-industrial levels (Intergovernmental Panel on Climate Change 2018).

In fact, according to the IPCC, "worsening food shortages and wildfires, and a mass die-off of coral reefs [may be seen] as soon as 2040 — a period well within the lifetime of much of the global population," (Davenport 2018). These changes will increase in severity as the average global temperature continues to rise. These findings are also corroborated in the congressionally-mandated National Climate Assessment released in November 2018 (U.S. Global Change Research Program 2018). So, while it is important for the U.S., and the world, to make an economically and politically responsible transition from fossil fuel energy sources to carbon-free energy sources, there is a limited amount of time to make this transition. So, is natural gas the best bridge fuel? Are there alternative energy sources that could reduce carbon emissions even faster? Does the U.S. even need a bridge fuel, or are renewable, low-carbon energy sources readily deployable now? These questions are the focus of the current study.

It is hypothesized that natural gas will not reduce carbon emissions fast enough, and that in order to combat climate change, the U.S. will need to transition to a carbon-free energy source *now* (Hausfather 2016; U.S. Global Change Research Program 2018; Intergovernmental Panel on Climate Change, n.d.). Therefore, this study hypothesizes that nuclear energy would be a better bridge fuel. Nuclear energy has supplied roughly 20% of the U.S.'s electricity needs since 1990 while operating approximately 100 reactors (Holt 2014). The Nuclear Regulatory Commission

(NRC) has also begun issuing renewed operating licenses for the current nuclear reactor fleet. Initial 40-year licenses were "based on economic and antitrust considerations - not on limitations of nuclear technology," so if active reactors are still able to meet the NRC's updated requirements, they are able to receive a license for continuing operation (U.S. Nuclear Regulatory Commission 2015). Even so, the Tennessee Valley Authority's Watts Bar II reactor that began operation in 2016 is likely the last Generation II reactor the U.S. fleet will see built (Safer and Barczak 2015). Generation III and IV nuclear reactors boast a number of benefits over second generation reactors including designs that cut-down on licensing and construction time, capital cost, and waste produced (World Nuclear Association 2018a). They are also much easier to operate and contain fail-safe mechanisms that make them less vulnerable to operator error and external security threats (World Nuclear Association 2018a). Finally, and perhaps most pertinent, is the fact that nuclear reactors do not produce carbon emissions while generating energy (U.S. Energy Information Administration 2018g).

Nuclear energy technology is readily deployable *now* and replacing fossil fuel sources with nuclear energy will drastically reduce U.S. carbon emissions. On top of that, advanced nuclear reactor technology will be able to provide additional benefits in the very near future (World Nuclear Association 2018a). Given the extreme consequences of climate change reported on by the IPCC and NCA and the immediacy of their impact, the U.S. must transition away from fossil fuel energy sources to carbon-free sources as soon as possible. Nuclear energy is here and readily deployable to do just that. Should the U.S. truly need a bridge fuel in order to transition to a renewable energy future, this study hypothesizes that nuclear energy would be the best bridge fuel.

## METHODS

This study was performed as a meta-analysis to examine how eight chosen metrics impacted three energy sources both independently and in aggregate. Natural gas, nuclear energy, and renewables (combined utility-scale solar photovoltaics and onshore wind energy) were chosen as the three energy sources. This was done in order to first, compare natural gas to nuclear energy as a bridge fuel and to second, determine whether a bridge fuel is actually necessary. The eight metrics of comparison that were chosen for analysis include: cost, implementation speed, $CO_2$ emissions, public opinion, available capacity, environmental impact, reliability, and needed policy.

Data was gathered by searching both academic databases and grey-literature for articles pertaining to the three chosen energy sources and eight chosen metrics. The first ten pages of searches using the following databases were analyzed: Google, Google Scholar, EBSCO's Applied Science and Technology Full Text, Engineering Village's GeoBase, and EBSCO's GreenFile. Lowly cited articles were excluded, as were articles older than January 2009 whenever possible. Search terms and individual articles found are listed below by metric. Due to the diverse nature of the data collected and analyzed, the remainder of this section will be broken down by metric to detail the methods used independently on each.

### *Cost*

Levelized cost of energy (LCOE) allows energy sources to be compared across, "different technologies of unequal life spans, project size, different capital cost, risk, return, and capacities," (U.S. Department of Energy 2015a). For this reason, it is the metric of choice for the cost comparison. Databases were searched using the term "levelized cost of energy" paired individually with "natural gas," "nuclear," "nuclear energy," "solar" or "wind" and screened using the above-mentioned procedure. This yielded three articles (National Renewable Energy Laboratory 2018b; U.S. Energy Information Administration 2018e; Lazard 2017). Each of the three articles contained a LCOE value for natural gas, nuclear energy, wind, and solar. These values were converted to same unit, 2017$/MWh. Then, the median value of each source was calculated. The median was chosen rather than the mean as the median is not affected by outliers. Given the small sample size, it was difficult to identify outliers with confidence. Additionally, standard error was not provided in the publications for LCOE, so a weighted arithmetic mean was not possible. Therefore, the median is a superior measure of central tendency in this case.

In two cases, separate values were given for the LCOE of natural gas burned by combustion turbines (CT) and combined cycle turbines (NGCC). Therefore, the median LCOE was calculated separately for combustion turbines and combined cycle turbines. These numbers were then averaged using a 1:3 ratio to obtain a single LCOE for natural gas as a general source. This ratio was chosen because, "more than three-quarters of the planned capacity are from NGCC plant builds," (U.S. Energy Information Administration 2017a). Hence, it is the likely weight each of these generators will have on the LCOE of natural gas as a source. Additionally, for the LCOE of renewables, the median LCOE of both wind and solar were averaged to obtain a single, renewable LCOE. Finally, the three median LCOE values for natural gas, nuclear, and renewables were normalized by dividing each by the lowest of the three median LCOE values.

*Implementation Speed*

To determine the implementation speed, in years, of each energy source, the databases were searched using the terms "implementation speed," "construction speed," "timeline," "conception-to-production time," "construction time," and "build time" paired individually with "natural gas," "nuclear," "nuclear energy," "solar" or "wind" and screened using the above-mentioned procedure. This yielded ten articles (U.S. Energy Information Administration 2018c; Lazard 2017; U.S. Nuclear Regulatory Commission 2018a; Rollins, Tutmaher, and Pintcke 2012; U.S. Nuclear Regulatory Commission 2018b; American Wind Energy Association 2017; Parkes Solar Farm 2015; Berthélemy and Rangel 2015; Sovacool 2009; Greentech Media 2015). However, the information contained in each of the articles was nonuniform and therefore difficult to aggregate. Originally, the timeframe between project inception and energy production was sought, but many articles were only able to provide information on plant construction time. For this reason, a range was used to depict the longest and shortest potential time from project inception to energy production and the median of each range was calculated. Again, the median speed of both wind and solar were averaged to obtain a single, renewable implementation speed. Finally, the three median implementation speeds were normalized by dividing each value by the lowest of the three median implementation speeds.

It is worth noting, that given the difficulty of obtaining this information, a small, sub-study analysis was done using raw data provided by the NRC in order to determine the length of time it takes for the NRC to approve a nuclear reactor licensing application. From the list of combined licenses (COL) received by the NRC listed on its website, each of those having received a commission decision were analyzed to determine how long the process took (U.S. Nuclear Regulatory Commission 2018a). Of the eight COL applications, the length of time between when the application was tendered and when the commission issued a decision, was calculated. The approximate length of time it takes for the NRC to review a nuclear reactor licensing application was calculated by taking the mean of these values. Additionally, using this information, one-tail Student's t-tests with a significance level of 0.05 were performed to determine whether there was a significant difference in the review time for reactors built on greenfield or brownfield sites and applications seeking approval for a single reactor or multiple reactors.

*$CO_2$ Emissions*

To determine the $CO_2$ emissions for each studied energy source, the databases were searched using the terms “carbon emissions,” “$CO_2$ emissions,” “greenhouse gas emissions,” “emissions per unit energy,” and “emissions life cycle analysis” paired individually with “natural gas,” “nuclear,” “nuclear energy,” “solar” or “wind” and screened using the above-mentioned procedure. Only articles containing the full life-cycle analysis value of $CO_2$ emissions were used for each energy source to account for refining processes, transportation, etc. Ultimately, this yielded four articles (World Nuclear Association 2011; Hatch 2014; Weisser 2007; National Renewable Energy Laboratory, n.d.a). These values were converted to the same unit, $gCO_2$ equivalent/kWh. Next, using these values, the median $CO_2$ emissions per energy unit were calculated for each energy source. The median $CO_2$ emissions per energy unit of both wind and solar were averaged to obtain a single, renewable level of $CO_2$ emissions. Finally, the three median $CO_2$ emissions per energy unit were normalized by dividing each value by the lowest of the three median $CO_2$ emissions per energy unit. This concludes the three quantitative metrics. The following five metrics are considered to be qualitative metrics.

*Public Opinion*

To determine the public opinion of each energy source, the databases were searched using the term “public opinion” paired individually with “natural gas,” “nuclear,” “nuclear energy,” “solar” or “wind” and screened using the above-mentioned procedure. This yielded fourteen articles (Funk and Kennedy 2016; Bisconti 2016; Clarke et. al. 2015; Auter 2016; Lazard 2016; Olson-Hazboun 2017; Bisconti Research, Inc. 2016; Kennedy 2017; Bolger 2016;

Rosa and Dunlap 1994; Ernest & Young Global Limited 2017; Hamilton et. al. 2018; Thomas et. al. 2017; Jacquet et. al. 2018). Some of the articles contained information pertaining to all three energy sources, and others only contained information pertaining to one. Either way, each source's position was tabulated based on whether it was a positive, negative, or neutral public opinion of the use of each energy source. In articles that displayed this information quantitatively, a positive public opinion was considered to be one with an over 50% favorable response, anything under was considered an overall negative public opinion. See **Table 1**.

**Table 1: Public Opinion by Energy Source**
The table below shows how each of the articles analyzed for public opinion were tallied to determine an aggregate opinion. Both the representative percent and frequency of each opinion were also calculated.

| Reference | Natural Gas | | | Nuclear | | | Wind | | | Solar | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Positive** | **Negative** | **Neutral** | **Positve** | **Negative** | **Neutral** | **Positve** | **Negative** | **Neutral** | **Positve** | **Negative** | **Neutral** |
| Funk and Kennedy 2016 | | X | | | X | | X | | | X | | |
| Bisconti 2016 | | | | | | X | | | | | | |
| Clarke et. al. 2015 | | | X | | | X | | | | | | |
| Auter 2016 | | | | | | | X | | | X | | |
| Lazard 2016 | | | X | | | X | X | | | X | | |
| Olson-Hazboun 2017 | | | | | | | | | X | | | X |
| Biconti Research, Inc. 2016 | | | | X | | | | | | | | |
| Kennedy 2017 | | X | | | | | X | | | X | | |
| Rosa and Dunlap 1994 | | | | | | X | | | | | | |
| Bolger 2016 | | X | | | | X | X | | | X | | |
| Ernest & Young Global Ltd. 2017 | | | X | | | | | | | | | |
| Hamilton et. al. 2018 | | | | | | | X | | | X | | |
| Thomas et. al. 2016 | | | X | | | | | | | | | |
| Jacquet et. al. 2018 | | X | | | | | | | | | | |
| **Representative Percent** | 0.00% | 50.00% | 50.00% | 14.29% | 14.29% | 71.43% | 85.71% | 0.00% | 14.29% | 85.71% | 0.00% | 14.29% |
| **Frequency** | 0.00% | 50.00% | 50.00% | 14.29% | 14.29% | 71.43% | 85.71% | 0.00% | 14.29% | 85.71% | 0.00% | 14.29% |

From this table, the data was analyzed in two different manners by the representative percent and frequency. The representative percent was calculated by taking the total number of tallies in one column, for example Nuclear Positive (1), and dividing by the total number of tallies for that energy source, for example Nuclear (7). This then gives the representative percent of that opinion compared to the other opinions of that energy source. For Nuclear Positive that is $\frac{1}{7}$ = 14.29%. The frequency was calculated by taking the number of articles that held a particular opinion and dividing it by the total number of articles that held any opinion on that energy source. This then gives the frequency of that opinion occurring. In this case, the representative percent and the frequency were the same in each situation. However, were an article to bring up multiple opinions, the number of tallies for the representative percent and the frequency would be different, and therefore yield different results, as will be seen in other cases throughout this study. Therefore, this analysis was preserved for continuity. The public opinion of both wind and solar energy were averaged to determine the public opinion of renewables as a whole. Finally, the data was normalized using the following equation $\frac{(1-A)}{(1-B)}$ where $A$ is equal to the representative percent positive of that energy source and $B$ is equal to the representative percent positive of the energy source with the highest representative percent positive public opinion.

*Available Capacity*

To determine the available capacity of each energy source, the databases were searched using the terms "capacity," "available energy," "supply," "potential energy," and "potential available energy" paired individually with "natural gas," "nuclear," "nuclear energy," "solar" or "wind" and screened using the above-mentioned procedure. This yielded seventeen articles (U.S. Department of Energy 2015b; Fthenakis, Mason, and Zweibel 2009; Plumer 2013; Lu, McElroy, and Kiviluoma 2009; Fetter 2009; Nuclear Energy Institute 2018; Bradish 2008; Price and Blaise 2002; World Nuclear Association 2018b; National Renewable Energy Laboratory 2011; Shaner et. al. 2018; National Geographic 2011; U.S. Energy Information Administration 2018d; BP 2018; Flogas 2018; U.S. Department of Energy, n.d.c.; U.S. Energy Information Administration 2017b). As was the case with the public opinion data, some articles contained information pertaining to more than one energy source and others did not. The articles were tabulated based on the capacity they stated was available for that source of energy. For both natural gas and nuclear energy, this meant how much of the fuel source was still available in the earth. This was commonly expressed as number of years of supply left at current consumption. For both wind and solar energy, this meant the potential held by U.S. land mass to produce solar and wind energy, *i.e.* does the U.S. have enough land space to meet its energy needs with wind or solar. In the articles, this was commonly expressed as a percentage of energy needs the U.S. could expect to meet from these resources.

Once the tallies were accounted for, the data was analyzed in the same manner as the public opinion data above. The representative percent was calculated by taking the total number of tallies in one column and dividing by the total number of tallies for that energy source. This gave the representative percentage of that claim compared to the others within an energy source. The frequency of each claim was calculated by taking the total number of tallies in one column and dividing it by the total number of articles that made a claim related to that energy source. A range was then determined for each energy source based on either the amount of time the earth's supply was predicted to last, or the percentage of U.S. energy needs the source could be expected to meet. There was no consensus of the data, therefore it could not be normalized.

*Environmental Impact*

The databases were searched to determine the environmental impact of each energy source. This was done using the term "environmental impact" paired individually with "natural gas," "nuclear," "nuclear energy," "solar" or "wind" and screened using the above-mentioned procedure. This yielded seventeen articles (Union of Concerned Scientists, n.d.; U.S. Energy Information Administration 2018f; Wang et. al. 2014; Hernandez et. al. 2014; Saidur et. al. 2011; National Research Council 2007; Union of Concerned Scientists 2013b; U.S. Department of Energy n.d.a.; Rashad and Hammad 2000; Steinhauser, Brandl, and Johnson 2014; World Nuclear Association 2013; U.S. Energy Information Administration 2018g; Ewing 2008; Union of Concerned Scientists 2013a; Nunez 2014; U.S. Energy Information Administration 2018h;

National Energy Technology Laboratory 2014). As above, some articles contained information pertaining to more than one energy source and others did not. The articles were tabulated in a similar manner to those described above, with the environmental impact being described as the header of each column within each energy source. Once this was done, the tallies were analyzed in the two manners described above to determine the representative percent each environmental impact held within each energy source and how frequently that environmental impact was brought up when discussing that energy source. Finally, to normalize the data, the representative percent for each environmental impact by energy source was multiplied by the frequency of that environmental impact. These products, the weight of each environmental impact, were summed within each energy source. This gives the total weight of environmental impacts for each energy source. Those sums for wind and solar were then averaged to determine a single, renewable energy environmental impact score.

*Reliability*

To examine the reliability of each energy source, the databases were searched using the terms “reliability,” “resiliency,” and “security” paired individually with “natural gas,” “nuclear,” “nuclear energy,” “solar” or “wind” and screened using the above-mentioned procedure. This yielded twenty-three articles (Liss and Rowley 2018; Lofthouse, Simmons, and Yonk 2015a; Union of Concerned Scientists 2015; U.S. Department of Energy, n.d.b.; American Wind Energy Association, n.d.; Trabish 2017; Pinar Pérez et. al. 2013; Pfaffel, Faulstich, and Rohrig 2017; U.S. Energy Information Administration, n.d.; National Renewable Energy Laboratory, n.d.b.; Page 2017; Mu 2007; Brook et. al. 2014; Lofthouse, Simmons, and Yonk 2015b; Sisk 2017; National Renewable Energy Laboratory 2018a; Natural Resources Defense Council 2017; Panfil 2014; Smead 2010; Nuclear Energy Institute, n.d.; North American Electric Reliability

Corporation 2017; Comby, n.d.; Brown 2017). Some articles contained information that pertained to more than one energy source, but others only contained information pertaining to one. Either way, each article was tabulated based on whether it considered the energy source reliable, not reliable, or neutral. Again, the representative percent and frequency were calculated using the manner described above. The representative percent reliable of each wind and solar were averaged to determine a representative percent reliable for renewables as a group. Finally, in order to normalize the data, 1.00 was divided by each energy source's representative percent reliable. This was done rather than using the same equation used for public opinion to account for the absolute data in each case; however, the normalization is the same either way.

*Needed Policy*

Finally, to determine what policies would be needed in order to implement a wide-spread deployment of each energy source, the databases were searched using the terms "policy," "policy to implement," "favorable policy," "policies for," and "policies supporting" paired individually with "natural gas," "nuclear," "nuclear energy," "solar" or "wind" and screened using the above-mentioned procedure. This yielded thirteen articles (Cox et. al. 2015a; Cox et. al. 2015b; Nordhaus and Lovering 2016; Loris 2011; Wood Mackenzie 2015; Stein et. al. 2017; Congress.gov 2018; Tiemann and Vann 2015; Holt 2014; Friedman 2018; American Wind Energy Association 2018; Orvis et. al. 2017; National Academy of Engineering and National Research Council 2010). Some articles contained information pertaining to more than one energy source, whereas others did not. The data was tabulated in a similar manner to the environmental impact metric where each column header represented a policy brought up in at least one article, by energy source. The representative percent and frequency of each policy were calculated in the manner described above. Finally, in order to normalize the data, the weight of each policy was calculated by multiplying the representative percent and frequency of each policy by the implementation factor. This refers to whether or not the policy requires new implementation, or whether it maintains the status quo. For those policies that would require a new regulation or law be put into effect, their implementation factor is 1. For those policies currently in progress of being implemented, their implementation factor is 0.5. For those policies that maintain the status quo, and therefore do not need new implementation, their implementation factor is 0. Finally, these weights were then summed within each energy source. This gives the total weight of policies needed for each energy source. Those sums for wind and solar were then averaged to determine a single, renewable energy needed policy weight.

### *Multi-Criterion Decision Analysis*

Finally, after each metric was analyzed individually, the normalized data was placed in a table and summed, for every metric, within each energy source. This multi-criterion decision analysis (MCDA) yielded a final total number, or score, that can be used to compare the impact of the eight metrics on and across each energy source. Given that each metric's data was normalized to one, the lowest score is the best resultant case. This was done holding all eight metrics at equal value. However, by changing the weight of each metric in the MCDA, it is possible to play out different scenarios using the data based upon different value-systems.

## RESULTS

The eight metrics examined in this study provide insight into each energy source and contribute to its selection as an energy source of the future. **Table 2** details the results of this study, which are broken down further, by metric, below.

**Table 2: Results Organized by Metric and Energy Source**
This table details the results of this study and is organized by both the eight metrics evaluated (rows) and the three energy sources studied (columns). The grey rows for each metric contain the result in the units noted for the metric. The white rows for each metric contain the normalized result. Finally, the Total Score contains the sum of the normalized data in each column and the Total 'Wins' contains the number of metrics the energy source scored best in. Since the data for each metric was normalized to one, the energy source with the lowest total sum is the best-case scenario. This table displays that result holding each of the eight metrics at equal value, or equal weight.

| Metric | Natural Gas | Nuclear | Renewables |
|---|---|---|---|
| **Cost** | 1.02 | 1.73 | 1.00 |
| (2017$/MWh) | 54.79 | 92.60 | 53.65 |
| **Implementation Speed** | 1.14 | 3.06 | 1.00 |
| (years) | 2.85 | 7.66 | 2.50 |
| **CO2 Emissions** | 30.13 | 1.00 | 2.28 |
| (gCO2eq/kWh) | 482.00 | 16.00 | 36.50 |
| **Public Opinion** | 7.00 | 6.00 | 1.00 |
| (percent positive) | 0.00% | 14.29% | 85.71% |
| **Available Capacity** | 1.00 | 1.00 | 1.00 |
| (years/percentage) | 52.6 - 200 | 90 - forever | 50% forever |
| **Environmental Impact** | 1.56 | 1.00 | 1.07 |
| (weight) | 0.83 | 0.54 | 0.58 |
| **Reliability** | 2.33 | 1.00 | 2.12 |
| (percent reliable) | 42.86% | 100.00% | 47.22% |
| **Policy Needed** | 1.00 | 2.01 | 3.23 |
| (weight) | 0.14 | 0.27 | 0.44 |
| **Total Score** | 45.18 | 16.80 | 12.70 |
| **Total 'Wins'** | 1 | 3 | 3 |

*Cost*

Using the methods described above, renewables (combined utility-scale solar photovoltaics and onshore wind) were ultimately determined to have the lowest median LCOE at $53.65/MWh in 2017 dollars. Natural gas followed at a close second with a median LCOE of $54.79/MWh and nuclear was found to be the most expensive with a median cost of $92.60/MWh. It should be noted that every effort was made to determine each energy source's LCOE *before* tax incentives and subsidies were applied. Once the data was normalized to the lowest, least expensive, energy source, renewables were valued at 1.00, natural gas at 1.02, and nuclear energy at 1.73. See **APPENDIX A3**.

*Implementation Speed*

Renewables were determined to have the shortest implementation speed. The project inception to energy production timeline had a median of 2.50 years. This was again followed by natural gas, with a median timeline of 2.85 years, and lastly nuclear energy with a median timeline of 7.66 years. Once the data was normalized, renewables were valued at 1.00, natural gas was valued at 1.14, and nuclear energy at 3.06. See **APPENDIX A4**.

Additionally, a small sub-study analysis was done using raw data provided by the NRC to determine the length of time it takes for the NRC to approve a nuclear reactor licensing application. The average length of time between when the application was tendered and when the commission issued a decision, was 7.30 years. Additionally, using this information, one-tail Student's t-tests were performed to determine whether there was a significant difference in the review time for reactors built on greenfield or brownfield sites and applications seeking approval for a single reactor or multiple reactors. The P-value for the comparative analysis between greenfield and brownfield site applications was 0.19 and the P-value for the comparative analysis between single unit applications and multiple unit applications was 0.31. Neither of these P-values met the 0.05 significance level. Therefore, a single average is sufficiently representative of application review time for all reaction application types.

*$CO_2$ Emissions*

For the last of the quantitative metrics, $CO_2$ emissions, nuclear energy was determined to have the lowest median emissions throughout its entire lifecycle with a rate of 16.00 g$CO_2$equivalent/kWh. Renewables followed with a median lifecycle emissions rate of 36.50 g$CO_2$equivalent/kWh and lastly natural gas with a median lifecycle emissions rate of 482.00

$gCO_2$equivalent/kWh. Once normalized, nuclear energy was valued at 1.00, renewables at 2.28, and natural gas at 30.13. See **APPENDIX A5**.

*Public Opinion*

For the first of the qualitative metrics, each article was tallied based on whether it had a positive, negative, or neutral opinion of the energy source. The results of this tally are detailed in **Figure 1**. Natural gas was determined to have a negative public opinion 50.00% of the time and a neutral public opinion 50.00% of the time. Nuclear energy had a positive public opinion 14.29% of the time, a negative public opinion 14.29% of the time, and a neutral public opinion 71.43% of the time. Lastly, renewables had a positive public opinion 85.71% of the time and a neutral public opinion 14.29% of the time. These are the values for the representative percent calculation and, in this case, they are also equal to the frequency. When the highest percent positive public opinion is normalized to 1.00, renewables lead with a value of 1.00. In second is nuclear energy with a value of 6.00, and in third, natural gas with a value of 7.00. See **APPENDIX A6**.

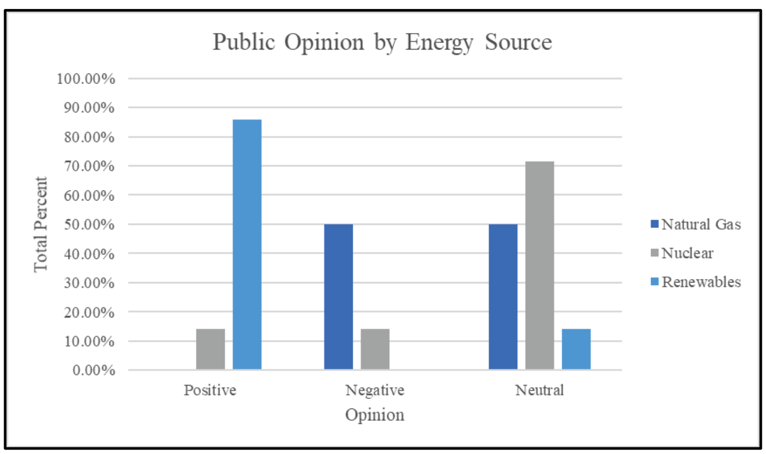


**Figure 1: Public Opinion by Energy Source**
The figure illustrates the total percent of time the public opinion of each energy source was found to be positive, negative, or neutral. Natural gas, shown in dark blue, was determined to have a negative public opinion 50.00% of the time and a neutral public opinion 50.00% of the time. Nuclear energy, shown in grey, had a positive public opinion 14.29% of the time, a negative public opinion 14.29% of the time, and a neutral public opinion 71.43% of the time. Lastly, renewables, shown in light blue, had a positive public opinion 85.71% of the time and a neutral public opinion 14.29% of the time. Here, these are both the values of the representative percent and frequency.

*Available Capacity*

As mentioned above, the data in this metric was very nonuniform and therefore difficult to analyze. For natural gas, the available capacity ranged from 52.6 to 200 years with no two sources sharing any estimate within 35 years of another. The same can be said for nuclear energy whose estimates ranged from 90 years to over 30,000 years with the likes of future advanced reactors. As for renewables, approximately half of the articles estimated that combined wind and solar had the potential to meet well-above the U.S.'s energy needs. The other half of the articles seemed to estimate that renewables would never be able to produce 100% of the U.S.'s energy needs, and rather, would cap at approximately 80% of U.S. energy needs. However, the range for this metric was extremely broad, and no two articles ever expressed the same opinion, rather just similar opinions. Therefore, it has been determined that not enough data is readily available to understand the future available capacity for these energy sources. As National Geographic pointed out in a recent article, any estimate of resources underground is just that, an estimate, and, one that will change based on advancements in both the technology using the resource and the models that allows humans to make these estimates (National Geographic 2011). The data was not normalized, and rather, each energy source was simply assigned a value of 1.00. For a more detailed view of the tally sheet and each of the estimates, please see **APPENDIX A7**.

*Environmental Impact*

To determine the environmental impact of each energy source, every possible environmental impact discussed in the selected articles was tabulated. Each of the sources were listed in the left-hand row of the table. The data was then tallied to determine which environmental issues were mentioned for each energy source. The representative percent of each issue was calculated, as was the frequency of each issue. The top four issues pertaining to natural gas were methane leaks, earthquakes, water pollution, and land and water use. Each of these issues represented 16.67% of the issues raised, so in total, they represented 66.67% of all issues raised. They were each brought up with a frequency of 100% - meaning that every article surveyed pertaining to the environmental impacts of natural gas, mentioned these four issues. These, along with the remaining five issues mentioned for natural gas: air pollution (Representative Percent: 12.50%, Frequency: 75.00%), wildlife disturbances (RP: 8.33%, F: 50.00%), drilling (RP: 4.17%, F: 25.00%), disruption to people/communities (RP: 4.17%, F: 25.00%), and fracking fluid leakage (RP: 4.17%, F: 25.00%), were then used to calculate the total weight of environmental issues for natural gas. Each of the issues' representative percent was multiplied by its frequency to determine a weight of the issue, and then these were summed across all issues to determine the total weight of natural gas's environmental impact, 0.83 out of a possible 1.00.

As for nuclear energy, the same process was followed, but only four unique issues were raised. They were fuel/waste disposal (RP: 42.86%, F: 75.00%), radioactive release (RP: 28.57%, F: 50.00%), waste heat (RP: 14.29%, F: 25.00%) and human health (RP: 14.29%, F: 25.00%). The total environmental impact weight of nuclear energy was 0.54 out of a possible 1.00. For wind energy, eight unique issues were identified. In descending order of weight, they were: wildlife deaths (RP: 25.00%, F: 80.00%), habitat alteration (RP: 25.00%, F: 80.00%), ecosystem structure (RP: 12.50%, F: 40.00%), land use (RP: 12.50%, F: 40.00%), noise pollution (RP: 6.25%, F: 20.00%), effect on radar (RP: 6.25%, F: 20.00%), human health (RP: 6.25%, F: 20.00%), and visual interference (RP: 6.25%, F: 20.00%). The final environmental impact weight of onshore wind energy was determined to be 0.55 out of a possible 1.00. Finally, for utility-scale solar photovoltaics, seven issues were identified. In descending order of weight, they were: land and water use (RP: 35.71%, F: 100.00%), hazardous materials use (RP: 21.43%, F: 60.00%), biodiversity (RP: 14.29%, F: 40.00%), lack of recycling options (RP: 7.14%, F: 20.00%), waste materials (RP: 7.14%, F: 20.00%), soil change (RP: 7.14%, F: 20.00%), and human health (RP: 7.14%, F: 20.00%). The total environmental impact weight of solar energy was determined to be 0.60 out of a possible 1.00. Wind and solar energies' environmental impact weights were then averaged to determine a single impact weight from renewables, which was 0.58. For more detail on the individual weight of each environmental issue and a detailed tally of the issues with links to their sources, please see **APPENDIX A8**.

*Reliability*

The reliability of each energy source was analyzed much the same way as the public opinion. The articles were broken-down and tabulated based on whether they argued the energy source was reliable, unreliable, or whether they remained neutral. Natural gas was determined to be reliable 42.86% of the time, unreliable 14.29% of the time, and neutral 42.86% of the time. Nuclear energy was noted as 100.00% reliable. As for wind energy, it was determined to be reliable 50.00% of the time, unreliable 16.67% of the time, and neutral 33.33% of the time. Finally, solar energy was found reliable 44.44% of the time, unreliable 22.22% of the time, and neutral 33.33% of the time. These are the values for the representative percent calculation but in this case, they are also equal to the frequency. The percent reliable for wind and solar were averaged to determine the total percent reliability for renewables at 47.22%. When the highest percent reliable value is normalized to 1.00, nuclear energy leads with a value of 1.00. In second are renewables with a value of 2.12, and in third is natural gas with a value of 2.33. See **APPENDIX A9**.

*Needed Policy*

Finally, to determine the policies needed in order to implement the expansion of each energy source, every possible policy discussed in the selected articles was placed at the top of a column in a table. Each of the sources were listed in the left-hand row of the table. As mentioned above, the data was then tabulated to determine which policies were mentioned for each energy source. The representative percent of all issues was calculated, as was the frequency of each issue. Eight unique policies were mentioned for natural gas. In descending order of representative percent and frequency, they were: maintaining the Safe Drinking Water Act exemption for fracking, otherwise known as the Halliburton Loophole (RP: 18.18%, F: 33.33%, Implementation Factor: 0), decreasing or not implementing increased environmental standards like the methane rule (RP: 18.18%, F: 33.33%, IF: 0.5), increasing the U.S. land area open to drilling, such as the Outer Continental Shelf (RP: 18.18%, F: 33.33%, IF: 1), eliminating subsidies for biofuels (RP: 9.09%, F: 16.67%, IF: 1), decreasing federal permitting rates/policies (RP: 9.09%, F: 16.67%, IF: 1), empowering state laws over federal laws (RP: 9.09%, F: 16.67%, IF: 1), keeping the Trump Administration from implementing its proposed rule on grid reliability and resilience pricing (RP: 9.09%, F: 16.67%, IF: 0), and making way for the 'shale revolution' (RP: 9.09%, F: 16.67%, IF: 0). The representative percent, frequency, and implementation factor were then multiplied for each policy to determine the weight of said policy. Lastly, the weight of each policy was summed to determine the total weight of needed policies for natural gas. This value was calculated as 0.14 out of a possible 1.00.

The same process was followed for nuclear energy, wind, and solar. For nuclear energy, ten individual policies were suggested. In order of decreasing representative percent and frequency, these were: finding a solution for nuclear waste/the Nuclear Waste Policy

Amendments Act of 2018 (RP: 21.43%, F: 50.00%, IF: 1), providing financial support (RP: 14.29%, F: 33.33%, IF: 1), supporting nuclear research and development (RP: 14.29%, F: 33.33%, IF: 1), implementing wider net-metering (RP: 7.14%, F: 16.67%, IF: 1), maintaining CAFÉ standards (RP: 7.14%, F: 16.67%, IF: 0), creating state energy goals (RP: 7.14%, F: 16.67%, IF: 1), speeding-up the nuclear licensing process (RP: 7.14%, F: 16.67%, IF: 1), implementing the Trump Administration's proposed rule on grid reliability and resilience pricing (RP: 7.14%, F: 16.67%, IF: 1), educating the public (RP: 7.14%, F: 16.67%, IF: 1), and supporting the current fleet (RP: 7.14%, F: 16.67%, IF: 1). The total weight of all needed policies for nuclear energy was calculated as 0.27 out of a possible 1.00.

The results for solar and wind were determined to be the same, as all the suggested policies applied to renewables as a whole. Twelve unique policies were suggested. In order of decreasing representative percent and frequency, they were: production tax credits (RP: 16.67%, F: 75.00%, IF: 1), investment tax credits (RP: 16.67%, F: 75.00%, IF: 1), implementing renewable energy or electricity portfolio standards (RP: 11.11%, F: 50.00%, IF: 1), implementing wider net metering (RP: 11.11%, F: 50.00%, IF: 1), implementing feed-in tariffs (RP: 5.56%, F: 25.00%, IF: 1), keeping the Trump Administration from implementing its proposed rule on grid reliability and resilience pricing (RP: 5.56%, F: 25.00%, IF: 0), implementing other financial incentives (RP: 5.56%, F: 25.00%, IF: 1), maintaining CAFÉ standards (RP: 5.56%, F: 25.00%, IF: 0), supporting research and development (RP: 5.56%, F: 25.00%, IF: 1), creating state energy goals (RP: 5.56%, F: 25.00%, IF: 1), implementing renewable-friendly interconnection standards (RP: 5.56%, F: 25.00%, IF: 1), and supporting private investment (RP: 5.56%, F: 25.00%, IF: 1). The total weight of all needed policies for renewables was calculated as 0.44 out of a possible 1.00. For more detail on the individual weight of each policy and a detailed table with links to sources, please see **APPENDIX A10**.

*Multi-Criterion Decision Analysis*

Finally, all of the calculated weights for each metric and each energy source were transferred into a table like **Table 2**. The weight of each metric within each energy source were then summed to determine the ultimate impact on that energy source. Holding the value of each metric the same, renewables led with a score of 12.70, followed by nuclear energy with a score of 16.80, and in last place natural gas with a score of 45.18. This shows that while nuclear energy would be a better bridge fuel than natural gas, the U.S. does not actually need a bridge fuel. Renewables are readily deployable now. See **Table 3**. And yet, it isn't every case where each of the eight metrics are valued equally. So, the current study also developed a Final MCDA Tool that allows for scientists, policymakers, academics, etc. to change the weight of each metric to see how that changes the scores. See **Table 4**. All raw data is provided in **APPENDIX A1**.

**Table 3: Final Multi-Criterion Decision Analysis Tool**
This table details the final, normalized weight of each metric for each energy source. The energy source with 1.00 as its weighted score in a particular metric would be considered the 'best' in that metric. Therefore, the lowest Total Weighted Score is considered the 'best' overall. This table represents the case where each metric is valued equally. However, a weight column has been provided so that scientists, policymakers, academics, etc. can easily change the weight, *i.e.* value, of each metric in order to play-out different scenarios.

| Metric | Weight | Natural Gas | Nuclear | Renewables |
|---|---|---|---|---|
| Cost | 1 | 1.02 | 1.73 | 1.00 |
| Implementation Speed | 1 | 1.14 | 3.06 | 1.00 |
| CO2 Emissions | 1 | 30.13 | 1.00 | 2.28 |
| Public Opinion | 1 | 7.00 | 6.00 | 1.00 |
| Available Capacity | 1 | 1.00 | 1.00 | 1.00 |
| Environmental Impact | 1 | 1.56 | 1.00 | 1.07 |
| Reliability | 1 | 2.33 | 1.00 | 2.12 |
| Policy Needed | 1 | 1.00 | 2.01 | 3.23 |
| **Total Weighted Score** | | 45.18 | 16.80 | 12.70 |

**Table 4: Example Situation Using Final MCDA Tool**
This table gives an example of a situation in which cost has been weighted 10 times greater and reliability has been weighted 5 times greater than the remaining metrics. Additionally, $CO_2$ Emissions was removed entirely. In this scenario, renewables still represent the best-case scenario, but the rankings of natural gas and nuclear have flipped.

| Metric | Weight | Natural Gas | Nuclear | Renewables |
|---|---|---|---|---|
| Cost | 10 | 10.20 | 17.30 | 10.00 |
| Implementation Speed | 1 | 1.14 | 3.06 | 1.00 |
| CO2 Emissions | 0 | 0.00 | 0.00 | 0.00 |
| Public Opinion | 1 | 7.00 | 6.00 | 1.00 |
| Available Capacity | 1 | 1.00 | 1.00 | 1.00 |
| Environmental Impact | 1 | 1.56 | 1.00 | 1.07 |
| Reliability | 5 | 11.65 | 5.00 | 10.60 |
| Policy Needed | 1 | 1.00 | 2.01 | 3.23 |
| **Total Weighted Score** | | 33.55 | 35.37 | 27.90 |

## DISCUSSION

The looming threat of climate change is growing harder and harder to ignore. Both the IPCC's 2018 Special Report (Intergovernmental Panel on Climate Change, n.d.) and the United States' 4$^{th}$ National Climate Assessment (U.S. Global Change Research Program 2018), discuss the need for immediate, rapid, extensive mitigation and adaptation efforts to reduce the chances of confronting the worst consequences of climate change. As mentioned above, the greatest contributor to anthropogenic climate change is greenhouse gas emissions and, in the U.S., the largest source of those emissions is the energy sector. It has been suggested by academics and policymakers alike that while renewables may not be ready for scale-up in the near term, in order to reduce greenhouse gas emissions, natural gas may be used as a bridge fuel. Natural gas has roughly half the carbon emissions of coal for the equivalent energy unit generated, and, thanks to recent advancements in drilling technologies, natural gas has seen a rapid reduction in price in the U.S. (Kerr 2010). And yet, due to the severe consequences laid out by the IPCC and NCA and the brief timeline left for action, the need to reduce greenhouse gas emissions by more than that provided by natural gas is critical. Therefore, this study hypothesized that due to its extremely low level of lifecycle carbon emissions, nuclear energy should be the bridge fuel that the U.S. turns to in order to combat climate change.

The study also looked at whether or not a bridge fuel was truly necessary. Meaning, are renewables capable of addressing climate change? Is there something holding them back that requires the need for a bridge fuel? As shown above, the results of this study say otherwise. In fact, renewables, here combined onshore wind and utility-scale solar photovoltaics, out-perform both natural gas and nuclear in almost every case imaginable. Therefore, the entire concept of a bridge fuel is unnecessary. Renewables are readily deployable now to combat climate change.

*Cost*

Across each of the eight metrics, natural gas, nuclear energy, and renewables were analyzed and compared to determine the best. While some metrics came out as expected, other results were quite surprising. The levelized cost of energy was examined without including tax credits, incentives, and subsidies for any energy source and, even so, renewables were revealed as the cheapest energy source, albeit not by much. But the fact that they are competitive with natural gas, without financial incentives, is somewhat surprising given that the narrative of the natural gas industry would have it believed otherwise. Therefore, one of the key arguments for natural gas as a bridge fuel, the fact that it is more cost-effective than renewables, was found to be false. However, as expected, nuclear energy came in as the most expensive energy source.

*Implementation Speed*

Rankings did not change with the review of implementation speed. Throughout the data collection process, finding robust data for this metric proved difficult due to the unstandardized timing process. Construction times were often reported intermixed with licensing times and full project timelines. However, again renewables resulted in the quickest implementation time followed closely by natural gas and nuclear energy in last. It is worth noting, though, that renewables individually would flank either side of natural gas, with solar panels being a speedier installation and wind turbines proving slightly slower than gas.

*$CO_2$ Emissions*

Given the interest of this study in the face of anthropogenic climate change, it is needless to say that this metric is one of great importance. It is also the first where nuclear energy got a chance to really shine. It is important to look at the entire life cycle analysis of energy sources when analyzing greenhouse gas emissions. While certain energy sources are carbon-neutral when burned, like biomass, throughout the growing, harvesting, refining, and transportation processes, they often rack up carbon emissions of their own (Harvey and Heikkinen, 2018). The same is the case with both nuclear energy and renewables. While they produce significantly less carbon emissions than natural gas as their fuel source does not itself emit greenhouse gases, throughout their entire lifecycle, they are associated with a small amount of carbon emissions. The mining processes used to excavate uranium for nuclear energy and additional precious metals for solar panels do incur some greenhouse gas emissions, as do their refining and transportation. While these are still much better choices than fossil fuels, as can be exemplified by the magnitude of difference between the energy sources (natural gas produces 30 times the amount of $CO_2$ emissions as nuclear energy), it is important that they are still managed sustainably throughout their entire lifecycle to keep emissions as low as possible.

*Public Opinion*

Public opinion proved to be another surprising category. Again, data from reputable sources was not always readily available, but of those screened, renewables came out ahead. However, given that the survey questions were not standardized across each source study, a few noteworthy points were discovered. Ultimately, natural gas came in last as no survey had given it a favorable public opinion. While half of those screened were neutral, others reflected a negative public opinion of natural gas. However, multiple sources eluded to the importance of framing when conducting these surveys. For example, referring to natural gas recovery as “fracking” as opposed to “shale development” would potentially lead the public to respond to questions differently (Clarke et. al. 2015). The same can also be said for nuclear energy. This study found that overall, nuclear had a relatively neutral public opinion. This came from the fact that while the public was generally supportive of the current fleet, once asked about siting a new reactor, a “not in my backyard” or NIMBY state of mind took over (Rosa and Dunlap 1994). Standardizing the framing of public opinion surveys would likely lead to less biases and more understanding when it comes to the complexities of these energy sources. Yet, for the time being, renewables came out far ahead of both natural gas and nuclear energy, with a great majority of the public supporting the research, development, and deployment of renewable energy technologies.

*Available Capacity*

Unfortunately, this is another metric where data collection proved difficult. The intention behind looking at available capacity was to see just how long non-renewable resources were predicted to last and whether or not renewables would be able to meet all of America’s energy needs. Ultimately, it seems there is not enough data available in the field to form a consensus. Predictions ranged from 50 to 200 years for natural gas, and from 90 to 30,000 years for nuclear energy, depending on the development of advanced reactors. The case for both wind and solar was similar. Some articles expressed that with the solar and wind potential of the U.S., renewables would have no problem meeting energy needs if they were deployed at scale (U.S. Department of Energy n.d.c.; Lu, McElroy, and Kiviluoma 2009; National Renewable Energy

Laboratory 2011). Still, others stated that renewables would only ever be able to meet roughly 80% of U.S. energy needs and that the rest would need to be addressed by fossil fuels or other solutions like nuclear, hydropower, or energy storage (Shaner et. al. 2018). For both fossil fuels and renewables, it seems as though an estimate is only just that, an estimate (National Geographic 2011). Predicting the advancements in technologies that would allow for the extended use of underground mineral resources is still in its infancy, as is predicting the amount of said minerals left underground. This uncertainty in capacity of non-renewable and fossil fuel resources is fighting the intermittency of renewable resources such as wind and solar – making the available capacity of both unpredictable. Ultimately, it is the opinion of this study that while more research is needed to refine the data underpinning this metric, it is not something that should stall action at this point given the robust display of the other metrics.

*Environmental Impact*

It was decided that environmental impact should be examined separately from $CO_2$ emissions as there is significantly more to the environment than greenhouse gas emissions. This metric was another with some surprise results. Despite their green advertising, both solar and wind proved to have more environmental impacts than even nuclear energy. While nuclear energy comes with its own baggage, namely radioactive waste and radioactive release, it was not so much as to outweigh the diverse array of concerns surrounding renewables. However, perhaps there is something to be said here on the relative age of each technology. Much of the early environmental concerns surrounding nuclear energy have boiled down to the two main concerns mentioned above. They each loom with a greater threat than any individual concern facing renewables, but the sheer number of those facing renewables ultimately won out. These included concerns over wildlife, habitat alteration, and land use. Given the large land space that both solar and wind energy need to produce a given amount of energy compared to a nuclear reactor, significantly more wildlife is being affected by the construction of solar panels and wind turbines. As for natural gas, outside of $CO_2$ emissions, the major concerns generally related to fracking and drilling. Widespread concern over methane leakage seems to have caught on as it was frequently mentioned as a major environmental concern. Earthquakes and water shelf pollution due to fracking were also frequently mentioned when discussing the environmental impacts of natural gas. Again, while some choices have proven to be better than others, this goes to illustrate the importance of managing all environmental impacts of each energy source in order to sustainably, and safely, make use of natural resources.

*Reliability*

The reliability of each energy source was analyzed similarly to public opinion in that it was either deemed reliable, unreliable, or neutral. While this set-up makes the analysis much simpler, it is important to remember the shades of grey that go into each decision. A number of factors contribute to whether or not an energy source is deemed reliable. Here, nuclear energy came out far in the lead as the most reliable energy source, in fact, it was considered 100% reliable. Another way of viewing this though, is that it is the most predictable energy source. Comparatively, both solar and wind are intermittent energy sources, meaning that a wind turbine or a solar panel cannot continuously generate energy. Sometimes the wind is not blowing, and the sun is not shining. As for natural gas, the major area of concern came from the volatility of pricing over the recent decades and as the seasons shift (Smead 2010). That is not to say that both renewables and natural gas are unreliable energy sources, but that when compared to nuclear, their ability to generate energy is more dependent on externalities than is nuclear energy.

*Needed Policy*

Finally, needed policy – it is important to incorporate this metric into the current study to illustrate the effect that policy and policymakers have on America's energy choices and decisions. The current set of policies implemented in the energy sector tend to favor natural gas, shown by it having the lowest score in this metric. This means that natural gas most benefits from the policy status quo and that in order to best implement either nuclear energy or renewables, new policies are likely necessary. Some of the policies screened in the current study are being implemented, but will either be phasing out soon, like tax credits, or need to be strengthened in order to better facilitate renewables or nuclear energy, like interconnection standards. These are important as policy plays a very big role in supporting energy in America.

The federal government has long provided the natural gas industry with subsidies to help keep consumer prices low (U.S. Energy Information Administration 2018b) and has also frequently led the charge on both nuclear and renewable energy research and development through agencies like the Advanced Research Projects Agency – Energy (Advanced Research Projects Agency – Energy – U.S. Department of Energy 2018). However, government policies have also diminished energy development in the past by implementing updated environmental standards and disallowing public lands to be used for development. All of this is to say that government policies can either help or hinder an energy source. Many times, these policies are for the betterment of the country. Environmental standards are necessary to keep air and water from being polluted. Safety regulations keep workers safe from the many hazards associated with energy development. And yet, many times these policies are often slow to change or even counter to what has been proven the best path forward. Such is the case, currently. While renewables have won out in many of metrics, it is in needed policy that natural gas shines. This goes to show that the policy status quo favors natural gas despite its obvious failures at meeting emissions reductions needs in the face of global warming – something that must change as the U.S. begins to seriously address climate change.

*Multi-Criterion Decision Analysis*

While each individual metric has led to its own insights on the U.S. energy sector, when they all come together, they are able to truly give insight into America's energy choices for its future. A MCDA Tool was created as part of this study to aid scientists, policymakers, academics, etc. in making more informed decisions about America's energy future. When all eight metrics are weighted equally, renewables rank as the best energy source. However, even when $CO_2$ emissions are removed from the equation entirely (given a weight of 0), renewables still emerge as the best energy source. There are many different ways weights could be assigned based on different energy scenarios, but it proves difficult to find a scenario where renewables do not come out on top. While natural gas and nuclear energy may shift, based on the individual situation, renewables are consistently the best. The MCDA Tool is available in **APPENDIX A2** and it is suggested that readers try out situations for themselves to demonstrate the robustness of the study's results. Ultimately, renewables are the best energy source for America's future and are readily deployable now. A bridge fuel is unnecessary.

*Limitations and Future Study*

As stated above, given the fact that renewables consistently come out on top no matter the various weights assigned, the results of the current study have proven to be robust. And yet, it is also important to discuss the study's limitations. More than anything else, this study was limited by time. There is a wide array of data available to sort through, and other databases and search terms could be used to provide a more exhaustive sampling of data. Given the short timeframe of the study, many of the article's raw data files were inaccessible. Additionally, for this reason, error analysis was not able to be performed. Gaining access to the raw data files and the standard deviations associated with their calculations would have allowed for an error analysis and additional hypothesis testing. Were the study to be replicated, using raw data rather than aggregated data would likely increase the accuracy and precision of the MCDA Tool.

Additionally, increasing the number of variables for each metric or adding additional metrics would help to make the MCDA Tool more robust. For example, the risk associated with each environmental impact or the probability of it actually happening could be factored into the environmental impact assessment. Other metrics such as workforce development or contribution to the gross domestic product could be researched and added to the MCDA Tool to add a layer of complexity. It is also worth noting that currently, given the difference in the range of the normalized data, this results in a slightly different impact of each metric on the energy source's final score. This can be corrected by normalizing the sum of the data per metric in the MCDA Tool. However, the rankings remain the same in either case.

Finally, the study was limited by the availability of data. Due to the scope of many of the metrics, there were few sources able to provide the needed information. For example, when researching cost data, while many articles discussed the cost associated with each energy source, they all traced back to the same raw data available from the U.S. Energy Information Agency (EIA). This made finding differing opinions difficult, and those that did exist were often not on par with the quality provided by the EIA. Additionally, due to the heightened security associated with both nuclear energy and natural gas drilling, some information was simply inaccessible to the general public. But while these different factors have limited the current study, they also provide potential for future studies on the subject.

*Conclusions*

In conclusion, while nuclear is indeed a better bridge fuel than natural gas, ultimately, the question of the best bridge fuel is unnecessary, and perhaps a distraction from the key point. The United States does not need a bridge fuel in order to get to a renewable energy future. Renewable energy sources like wind and solar are readily deployable now. In order to avoid the worst consequences of climate change, the U.S. needs to make a rapid, widespread transition from fossil fuel energy sources to renewable energy sources as soon as possible. Other energy sources like nuclear energy, hydropower, and geothermal will remain useful in specific regions, but overarchingly, wind and solar have proven to be the energy sources of the future. In order to combat climate change, the United States needs to begin this energy transition now.

**ACKNOWLEDGEMENTS**

The author would like to thank Samuel Brinton of Deep Isolation Inc., Dr. Daniel S. Zachary of Johns Hopkins University, Dr. Michael Schwebel of Johns Hopkins University, and Benjamin K. Gibbs, MD/PhD Candidate of the University of Kansas Medical Center for their help, advice, guidance, and support while collecting and analyzing the data for this study.

**BIOGRAPHICAL SKETCH**

Stephanie Dresen received her undergraduate degree from the University of Wisconsin – Madison where she studied Biochemistry and Environmental Studies. She is currently studying at Johns Hopkins University to receive her Master of Science in Energy Policy and Climate. Ms. Dresen currently works for the Missouri Department of Economic Development – Division of Energy as an Energy Policy Analyst. This piece reflects work undertaken by the author at Johns Hopkins University and does not reflect the views of the State of Missouri.

**APPENDIX**

A1. Raw Data File

A2. MCDA Tool

A3. Cost Data Table

| Reference | Natural Gas | | Nuclear | Onshore Wind | Utility Solar PV |
|---|---|---|---|---|---|
| | Combustion Turbine | Combined Cycle | | | |
| Lazard 2017 | N/A | 60.00 | 147.50 | 45.00 | 47.50 |
| U.S. EIA 2018e | 85.10 | 49.00 | 92.60 | 59.10 | 63.20 |
| NREL 2018b | 59.24 | 30.64 | 64.34 | 41.87 | 62.30 |
| **Median** | 72.17 | 49.00 | 92.60 | 45.00 | 62.30 |
| **Average Median** | 54.79 | | 92.60 | 53.65 | |

A4. Implementation Speed Data Table

| Reference | Natural Gas | | Nuclear | Onshore Wind | Utility Solar PV |
|---|---|---|---|---|---|
| | Combustion Turbine | Combined Cycle | | | |
| U.S. EIA 2018c | 2.00 | 3.00 | 6.00 | 3.00 | 2.00 |
| Lazard 2017 | N/A | 2.00 | 5.75 | 1.00 | 0.75 |
| U.S. NRC 2018a | N/A | N/A | 7.30 | N/A | N/A |
| Rollins, Tutmaher, and Pintcke 2012 | N/A | 3.70 | N/A | N/A | N/A |
| U.S. NRC 2018b | N/A | N/A | 9.31 | N/A | N/A |
| AWEA 2017 | N/A | N/A | N/A | 3.25 | N/A |
| Berthélemy and Rangel 2015 | N/A | N/A | 9.27 | N/A | N/A |
| Parkes Solar Farm 2015 | N/A | N/A | N/A | N/A | 0.75 |
| Sovacool 2009 | N/A | N/A | N/A | 0.38 | 0.17 |
| Greentech Media 2015 | N/A | N/A | N/A | N/A | 1.50 |
| **Individual Median** | 2.00 | 3.00 | 7.30 | 2.00 | 0.75 |
| **Notes** | no real median | no real median, range represents different things, ground breaking, conception, etc. | | | |
| **Range** | 2.00 - 3.70 years | | 6.00 - 9.31years for full process; 5.75 years for construction | 3.00 - 4.25 for full process; 3 months - 1.00 year for construction | 0.75 - 2.00 years for full process; 0.17 - 1.50 years for construction |
| **Median** | 2.85 | | 7.66 | 3.63 | 1.38 |
| | | | | 2.50 | |

A5. $CO_2$ Emissions Data Table

| Reference | Natural Gas | | Nuclear | Onshore Wind | Utility Solar PV |
|---|---|---|---|---|---|
| | Combustion Turbine | Combined Cycle | | | |
| World Nuclear Association 2011 | 499.00 | 499.00 | 29.00 | 26.00 | 85.00 |
| Hatch 2014 | N/A | 478.00 | 18.50 | 10.50 | N/A |
| Weisser 2007 | 467.50 | 467.50 | 13.40 | 19.00 | 58.00 |
| NREL, n.d.a | 465.00 | N/A | 12.00 | 11.00 | 45.00 |
| **Median** | 482.00 | | 15.95 | 15.00 | 58.00 |
| **Average Median** | 482.00 | | 16.00 | 36.50 | |

A6. Public Opinion Data Table

| Reference | Natural Gas | | | Nuclear | | | Wind | | | Solar | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Positive** | **Negative** | **Neutral** | **Positve** | **Negative** | **Neutral** | **Positve** | **Negative** | **Neutral** | **Positve** | **Negative** | **Neutral** |
| Funk and Kennedy 2016 | | X | | | X | | X | | | X | | |
| Bisconti 2016 | | | | | | X | | | | | | |
| Clarke et. al. 2015 | | | X | | | X | | | | | | |
| Auter 2016 | | | | | | | X | | | X | | |
| Lazard 2016 | | | X | | | X | X | | | X | | |
| Olson-Hazboun 2017 | | | | | | | | | X | | | X |
| Biconti Research, Inc. 2016 | | | | X | | | | | | | | |
| Kennedy 2017 | | X | | | | | X | | | X | | |
| Rosa and Dunlap 1994 | | | | | | X | | | | | | |
| Bolger 2016 | | X | | | | X | X | | | X | | |
| Ernest & Young Global Ltd. 2017 | | | X | | | | | | | | | |
| Hamilton et. al. 2018 | | | | | | | X | | | X | | |
| Thomas et. al. 2016 | | | X | | | | | | | | | |
| Jacquet et. al. 2018 | | X | | | | | | | | | | |
| **Representative Percent** | 0.00% | 50.00% | 50.00% | 14.29% | 14.29% | 71.43% | 85.71% | 0.00% | 14.29% | 85.71% | 0.00% | 14.29% |
| **Frequency** | 0.00% | 50.00% | 50.00% | 14.29% | 14.29% | 71.43% | 85.71% | 0.00% | 14.29% | 85.71% | 0.00% | 14.29% |
| **Average Representative Percent Positive** | 0.00% | | | 14.29% | | | 85.71% | | | | | |

## A7. Available Capacity Data Table

| Reference | Natural Gas | | | | Nuclear | | | | | | Wind | | | | | Solar | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Estimate is an Estimate | 90 years | 52.6 years globally | 200 years | 200 years currently, 30,000 with advanced reactors | Estimate is an Estimate | 90 years | Multiply fleet by 5 | 954 Reactors Needed | FAR OUT with Advanced | 35% by 2050 | Increasing Turbine Height Increase Penatration | 80% with Solar need backup | 100% with Solar | WELL ABOVE | 35% by 2050 90% by 2100 | 100% Renewable | 80% with Wind need backup | WELL ABOVE |
| U.S. DOE 2015b | | | | | | | | | | | X | | | | | | | | |
| Fthenakis, Mason, and Zweibel 2009 | | | | | | | | | | | | | | | | X | | | |
| Plumer 2013 | | | | | | | | | | | | | | X | | | X | | |
| Lu, McElroy, and Kiviluoma 2009 | | | | | | | | | | | | | | | X | | | | |
| Fetter 2009 | | | | | X | | | | | X | | | | | | | | | |
| NEI 2018 | | | | | | | | X | | | | | | | | | | | |
| Bradish 2008 | | | | | | | | | X | | | | | | | | | | |
| Price and Blaise 2002 | | | | | | | | | | X | | | | | | | | | |
| World Nuclear Association 2018b | | | | | | | X | | | | | | | | | | | | |
| NREL 2011 | | | | | | | | | | | | | | | X | | | | |
| Shaner et. al. 2018 | | | | | | | | | | | | | X | | | | | X | |
| National Geographic 2011 | X | | | | | X | | | | | | | | | | | | | |
| U.S. EIA 2018d | | X | | | | | | | | | | | | | | | | | |
| BP 2018 | | | X | | | | | | | | | | | | | | | | |
| Flogas 2018 | | | | X | | | | | | | | | | | | | | | |
| U.S. DOE, n.d.c | | | | | | | | | | | | | | | | | | | X |
| U.S. EIA 2017b | | | | | | | | | | | | X | | | | | | | |
| **Representative Percent** | 25.00% | 25.00% | 25.00% | 25.00% | 14.29% | 14.29% | 14.29% | 14.29% | 14.29% | 28.57% | 16.67% | 16.67% | 16.67% | 16.67% | 33.33% | 25.00% | 25.00% | 25.00% | 25.00% |
| **Frequency** | 25.00% | 25.00% | 25.00% | 25.00% | 16.67% | 16.67% | 16.67% | 16.67% | 16.67% | 33.33% | 16.67% | 16.67% | 16.67% | 16.67% | 33.33% | 25.00% | 25.00% | 25.00% | 25.00% |

## A8. Environmental Impact Data Table

| Reference | Natural Gas | | | | | | | | | Nuclear | | | | Wind | | | | | | | | Solar | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Methane Leakage | Air Pollution | Drilling | Disturbing to People | Wildlife | Earthquakes | Fracking Fluid Leaks | Water Pollution | Land and Water Use | Radioactive Release | Waste Heat | Fuel Disposal | Human Health | Noise Pollution | Land Use | Effect on Radar | Human Health | Visual Interference | Wildlife Deaths | Ecosystem Structure | Habitat Alteration | Biodiversity | Land and Water Use | Hazardous Materials | Lack of Recycling Options | Waste Materials | Soil Change | Human Health |
| Union of Concerned Scientists, n.d. | X | X | | | X | X | | X | X | | | | | | | | | | | | | | | | | | | |
| U.S. EIA 2018f | X | X | X | X | X | X | X | X | X | | | | | | | | | | | | | | | | | | | |
| Wang et. al. 2014 | X | | | | | X | | X | X | | | | | | | | | | | | | | | | | | | |
| Hernandez et. al. 2014 | | | | | | | | | | | | | | | | | | | | | | X | X | | | | X | X |
| Saidur et. al. 2011 | | | | | | | | | | | | | | X | | | | X | X | X | X | | | | | | | |
| National Research Council 2007 | | | | | | | | | | | | | | | | | | | X | X | X | | | | | | | |
| Union of Concerned Scientists 2013b | | | | | | | | | | | | | | | X | | X | | X | | X | | | | | | | |
| U.S. DOE, n.d.a | | | | | | | | | | | | | | | | X | | | X | | X | | | | | | | |
| Rashad and Hammad 2000 | | | | | | | | | | | | | | | X | | | | | | | | X | | | | | |
| Steinhauser, Brandl, and Johnson 2014 | | | | | | | | | | X | | | | | | | | | | | | | | | | | | |
| World Nuclear Association 2013 | | | | | | | | | | X | X | X | X | | | | | | | | | | | | | | | |
| U.S. EIA 2018g | | | | | | | | | | | | X | | | | | | | | | | | | | | | | |
| Ewing 2008 | | | | | | | | | | | | X | | | | | | | | | | | | | | | | |
| Union of Concerned Scientists 2013a | | | | | | | | | | | | | | | | | | | | | | | X | X | | | | |
| Nunez 2014 | | | | | | | | | | | | | | | | | | | | | | | X | X | X | X | | |
| U.S. EIA 2018h | | | | | | | | | | | | | | | | | | | | | | X | X | X | | | | |
| National Energy Technology Laboratory 2014 | X | X | | | | X | | X | X | | | | | | | | | | | | | | | | | | | |
| **Representative Percent** | 16.67% | 12.50% | 4.17% | 4.17% | 8.33% | 16.67% | 4.17% | 16.67% | 16.67% | 28.57% | 14.29% | 42.86% | 14.29% | 6.25% | 12.50% | 6.25% | 6.25% | 6.25% | 25.00% | 12.50% | 25.00% | 14.29% | 35.71% | 21.43% | 7.14% | 7.14% | 7.14% | 7.14% |
| **Frequency** | 100.00% | 75.00% | 25.00% | 25.00% | 50.00% | 100.00% | 25.00% | 100.00% | 100.00% | 50.00% | 25.00% | 75.00% | 25.00% | 20.00% | 40.00% | 20.00% | 20.00% | 20.00% | 80.00% | 40.00% | 80.00% | 40.00% | 100.00% | 60.00% | 20.00% | 20.00% | 20.00% | 20.00% |
| **Weight** | 0.17 | 0.09 | 0.01 | 0.01 | 0.04 | 0.17 | 0.01 | 0.17 | 0.17 | 0.14 | 0.04 | 0.32 | 0.04 | 0.01 | 0.05 | 0.01 | 0.01 | 0.01 | 0.20 | 0.05 | 0.20 | 0.06 | 0.36 | 0.13 | 0.01 | 0.01 | 0.01 | 0.01 |
| **Sum Environmental Impact** | 0.83 | | | | | | | | | 0.54 | | | | 0.55 | | | | | | | | 0.60 | | | | | | |
| **Average Sum Environmental Impact** | 0.83 | | | | | | | | | 0.54 | | | | 0.58 | | | | | | | | | | | | | | |

## A9. Reliability Data Table

| Reference | Natural Gas | | | Nuclear | | | Wind | | | Solar | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reliable | Not Reliable | Neutral | Reliable | Not Reliable | Neutral | Reliable | Not Reliable | Neutral | Reliable | Not Reliable | Neutral |
| Liss and Rowley 2018 | X | | | | | | | | | | | |
| Lofthouse, Simmons, and Yonk 2015a | | | | | | | | | | | X | |
| Union of Concerned Scientists 2015 | | | | | | | X | | | X | | |
| U.S. DOE, n.d.b | | | | | | | | | | | | X |
| AWEA, n.d. | | | | | | | X | | | | | |
| Trabish 2017 | | | | | | | | | X | | | X |
| Pinar Pérez et. al. 2013 | | | | | | | | | X | | | |
| Pfaffel, Faulstich, and Rohrig 2017 | | | | | | | | | X | | | |
| U.S. EIA, n.d. | | X | | | | | | | | | | |
| NREL, n.d.b | | | | | | | | | X | | | |
| Page 2017 | X | | | | | | | | | | | |
| Mu 2007 | | | X | | | | | | | | | |
| Brook et. al. 2014 | | | | X | | | | X | | | X | |
| Lofthouse, Simmons, and Yonk 2015b | | | | | | | | X | | | | |
| Sisk 2017 | X | | | | | | X | | | | | |
| NREL 2018a | | | | | | | | | | X | | |
| NRDC 2017 | | | | | | | X | | | X | | |
| Panfil 2014 | | | | | | | X | | | X | | |
| Smead 2010 | | | X | | | | | | | | | |
| NEI, n.d. | | | | X | | | | | | | | |
| North American Electric Reliability Corporation 2017 | | | X | | | | | | | | | |
| Comby, n.d. | | | | X | | | | | | | | |
| Brown 2017 | | | | | | | X | | | | | |
| **Representative Percent** | 42.86% | 14.29% | 42.86% | 100.00% | 0.00% | 0.00% | 50.00% | 16.67% | 33.33% | 44.44% | 22.22% | 33.33% |
| **Frequency** | 42.86% | 14.29% | 42.86% | 100.00% | 0.00% | 0.00% | 50.00% | 16.67% | 33.33% | 44.44% | 22.22% | 33.33% |
| **Average Representative Percent Reliable** | 42.86% | | | 100.00% | | | 47.22% | | | | | |

## A10. Policy Needed Data Table

| Reference | Natural Gas | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Stay Out of the Way of the Shale Revolution | Proposed Rule on Grid Reliability and Resilience Pricing is Not Implemented | Keep SDWA Excemption As Is (Halliburton Loophole) | Empower States (State Laws Over Federal) | Decrease Federal Permitting Rates/Policies in Current Production Areas | Decrease/Do Not Implement Environmental Standards (Methane) | Increase Areas Open to Production (Outer Continential Shelf) | Eliminate Subsidies for Biofuels |
| Cox et. al. 2015a and Cox et. al. 2015b | | | | | | | | |
| Nordhaus and Lovering 2016 | X | | | | | | | |
| Loris 2011 | | | X | X | | | X | X |
| Wood Mackenzie 2015 | | | | | X | X | X | |
| Stein et. al. 2017 | | | | | | | | |
| Congress.gov 2018 | | | | | | | | |
| Tiemann and Vann 2015 | | | X | | | | | |
| Holt 2014 | | | | | | | | |
| Friedman 2018 | | | | | | X | | |
| AWEA 2018 | | X | | | | | | |
| Orvis et. al. 2017 | | | | | | | | |
| Engineering and National Research Council 2010 | | | | | | | | |
| **Representative Percent** | 9.09% | 9.09% | 18.18% | 9.09% | 9.09% | 18.18% | 18.18% | 9.09% |
| **Frequency** | 16.67% | 16.67% | 33.33% | 16.67% | 16.67% | 33.33% | 33.33% | 16.67% |
| **Implementation Factor** | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 0.50 | 1.00 | 1.00 |
| **Weight** | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.03 | 0.06 | 0.02 |
| **Sum Policy Needed** | 0.14 | | | | | | | |
| **Average Sum Policy Needed** | 0.14 | | | | | | | |

| Reference | Nuclear | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Support Nuclear R&D | Net Metering | CAFÉ Standards | State Goals | Provide Financial Support | Speed Up Processes | Implement Proposed Rule on Grid Reliability and Resilience Pricing | Figure Out Nuclear Waste (NWPA 18) | Educate the Public | Support Current Fleet | |
| Cox et. al. 2015a and Cox et. al. 2015b | | | | | | | | | | | |
| Nordhaus and Lovering 2016 | | | | | | | | | | X | |
| Loris 2011 | | | | | | | | | | | |
| Wood Mackenzie 2015 | | | | | | | | | | | |
| Stein et. al. 2017 | | | | | | X | | X | X | | |
| Congress.gov 2018 | | | | | | | | X | | | |
| Tiemann and Vann 2015 | | | | | | | | | | | |
| Holt 2014 | X | | | | X | | | X | | | |
| Friedman 2018 | | | | | | | | | | | |
| AWEA 2018 | | | | | | | | | | | |
| Orvis et. al. 2017 | | | | | | | X | | | | |
| Engineering and National Research Council 2010 | X | X | X | X | X | | | | | | |
| **Representative Percent** | 14.29% | 7.14% | 7.14% | 7.14% | 14.29% | 7.14% | 7.14% | 21.43% | 7.14% | 7.14% | |
| **Frequency** | 33.33% | 16.67% | 16.67% | 16.67% | 33.33% | 16.67% | 16.67% | 50.00% | 16.67% | 16.67% | |
| **Implementation Factor** | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | |
| **Weight** | 0.05 | 0.01 | 0.00 | 0.01 | 0.05 | 0.01 | 0.01 | 0.11 | 0.01 | 0.01 | |
| **Sum Policy Needed** | 0.27 | | | | | | | | | | |
| **Average Sum Policy Needed** | 0.27 | | | | | | | | | | |

| Reference | Wind | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Renewable Electricity Standards (Portfolio) | Feed-In Tariffs | PTC | ITC | Proposed Rule on Grid Reliability and Resilience Pricing Is Not Implemented | Other Financial Incentives | CAFÉ Standards | Support R&D | State Goals | Interconnection Standards | Net Metering | Support Private Investment | |
| Cox et. al. 2015a and Cox et. al. 2015b | X | X | X | X | | | | | | X | X | X | |
| Nordhaus and Lovering 2016 | | | X | X | | | | | | | | | |
| Loris 2011 | | | | | | | | | | | | | |
| Wood Mackenzie 2015 | | | | | | | | | | | | | |
| Stein et. al. 2017 | | | | | | | | | | | | | |
| Congress.gov 2018 | | | | | | | | | | | | | |
| Tiemann and Vann 2015 | | | | | | | | | | | | | |
| Holt 2014 | | | | | | | | | | | | | |
| Friedman 2018 | | | | | | | | | | | | | |
| AWEA 2018 | | | | | X | | | | | | | | |
| Orvis et. al. 2017 | | | | | | | | | | | | | |
| Engineering and National Research Council 2010 | X | | X | X | | X | X | X | X | | X | | |
| **Representative Percent** | 11.11% | 5.56% | 16.67% | 16.67% | 5.56% | 5.56% | 5.56% | 5.56% | 5.56% | 5.56% | 11.11% | 5.56% | |
| **Frequency** | 50.00% | 25.00% | 75.00% | 75.00% | 25.00% | 25.00% | 25.00% | 25.00% | 25.00% | 25.00% | 50.00% | 25.00% | |
| **Implementation Factor** | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | |
| **Weight** | 0.06 | 0.01 | 0.13 | 0.13 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.06 | 0.01 | |
| **Sum Policy Needed** | 0.44 | | | | | | | | | | | | |
| **Average Sum Policy Needed** | 0.44 | | | | | | | | | | | | |

| Reference | Solar | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Renewable Electricity Standards (Portfolio) | Support R&D | State Goals | CAFÉ Standards | Other Financial Incentives | Feed-In Tariffs | Proposed Rule on Grid Reliability and Resilience Pricing Is Not Implemented | PTC | ITC | Interconnection Standards | Net Metering | Support Private Investment | | |
| Cox et. al. 2015a and Cox et. al. 2015b | X | | | | | X | | X | X | X | X | X | | |
| Nordhaus and Lovering 2016 | | | | | | | | X | X | | | | | |
| Loris 2011 | | | | | | | | | | | | | | |
| Wood Mackenzie 2015 | | | | | | | | | | | | | | |
| Stein et. al. 2017 | | | | | | | | | | | | | | |
| Congress.gov 2018 | | | | | | | | | | | | | | |
| Tiemann and Vann 2015 | | | | | | | | | | | | | | |
| Holt 2014 | | | | | | | | | | | | | | |
| Friedman 2018 | | | | | | | | | | | | | | |
| AWEA 2018 | | | | | | | X | | | | | | | |
| Orvis et. al. 2017 | | | | | | | | | | | | | | |
| Engineering and National Research Council 2010 | X | X | X | X | X | | | X | X | | X | | | |
| **Representative Percent** | 11.11% | 5.56% | 5.56% | 5.56% | 5.56% | 5.56% | 5.56% | 16.67% | 16.67% | 5.56% | 11.11% | 5.56% | | |
| **Frequency** | 50.00% | 25.00% | 25.00% | 25.00% | 25.00% | 25.00% | 25.00% | 75.00% | 75.00% | 25.00% | 50.00% | 25.00% | | |
| **Implementation Factor** | 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | | |
| **Weight** | 0.06 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.13 | 0.13 | 0.01 | 0.06 | 0.01 | | |
| **Sum Policy Needed** | 0.44 | | | | | | | | | | | | | |
| **Average Sum Policy Needed** | 0.44 | | | | | | | | | | | | | |

## REFERENCES


Advanced Research Projects Agency – Energy – U.S. Department of Energy. 2018. "ARPA-E Programs." Last modified September 18, 2018. https://arpa-e.energy.gov/?q=program-listing.

American Wind Energy Association. 2017. "Siting a Project." Last modified 2017. https://www.awea.org/wind-101/siting-a-project.

American Wind Energy Association. 2018. "Wind Industry Encouraged by FERC's Direction on Grid Resilience." Last modified January 9, 2018. https://www.awea.org/resources/press-releases/2018/wind-industry-encouraged-by-ferc%E2%80%99s-direction-on-gr.

American Wind Energy Association. n.d. "Wind Energy Helps Build a More Reliable and Balanced Electricity Portfolio." Accessed December 1, 2018. http://awea.files.cms-plus.com/AWEA%20Reliability%20White%20Paper%20-%202-12-15.pdf.

Auter, Zac. 2016. "In U.S., 73% Now Prioritize Alternative Energy Over Oil, Gas." *Gallup*, March 24, 2016. https://news.gallup.com/poll/190268/prioritize-alternative-energy-oil-gas.aspx?g_source=CATEGORY_ENVIRONMENT_AND_ENERGY&g_medium=topic&g_campaign=tiles.

Berthélemy, Michel and Lina Escobar Rangel. 2015. "Nuclear Reactors' Construction Costs: The Role of Lead-Time, Standardization, and Technological Progress." *Energy Policy* 82: 118-130. https://doi.org/10.1016/j.enpol.2015.03.015.

Bisconti, Ann S. 2016. "Public Opinion on Nuclear Energy: What Influences It." *Bulletin of the Atomic Scientists*, April 27, 2016. https://thebulletin.org/2016/04/public-opinion-on-nuclear-energy-what-influences-it/.

Bisconti Research, Inc. 2016. "Public Sees Nuclear Energy as Important, Survey Finds." Nuclear Energy Institute. Last modified October 2016. https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/national-public-opinion-survey-nuclear-energy-201610.pdf.

Bolger, Glen. 2016. "Post-Election Nation Clean Energy Survey." Public Opinion Strategies. Last modified November 13, 2016. http://www.conservativeenergynetwork.org/wp-content/uploads/2016/11/Clean-Energy-Survey4.pdf.

BP. 2018. "Natural Gas Reserves." Last modified 2018. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/natural-gas/natural-gas-reserves.html.

Bradish, David. 2008. "How many nuclear plants does it take to meet the world's energy needs?" NEI Nuclear Notes. Last modified March 21, 2008. http://neinuclearnotes.blogspot.com/2008/03/how-many-nuclear-plants-does-it-take-to.html.

Brook, Barry W., Agustin Alonso, Daniel A. Meneley, Jozef Misak, Tom Blees, and Jan B. van Erp. 2014. "Why Nuclear Energy is Sustainable and has to be Part of the Energy Mix." *Sustainable Materials and Technologies* 1-2: 8-16. https://doi.org/10.1016/j.susmat.2014.11.001.

Brown, Chris. 2017. "Wind Energy Strengthens Resilience, Reliability of US Power Grid." *Renewable Energy World*, May 18, 2017. https://www.renewableenergyworld.com/ugc/articles/2017/05/17/wind-energy-strengthens-resilience-reliability-of-us-power-grid.html.

Clarke, Christopher E., Philip S. Hart, Jonathon P. Schuldt, Darrick T.N. Evensen, Hilary S. Boudet, Jeffrey B. Jacquet, and Richard C. Stedman. 2015. "Public Opinion on Energy Development: The Interplay of Issue Framing Top-Of-Mind Associations, and Political Ideology." *Energy Policy* 81: 131-140. http://dx.doi.org/10.1016/j.enpol.2015.02.019.

Comby, Bruno. n.d. "The Benefits of Nuclear Energy." Accessed December 1, 2018. http://ecolo.org/documents/documents_in_english/BENEFITS-of-NUCLEAR.pdf.

Congress.gov. 2018. "H.R.3053 – Nuclear Waste Policy Amendments Act of 2018." Last modified May 14, 2018. https://www.congress.gov/bill/115th-congress/house-bill/3053.

Cox, Sadie, Suzanne Tegen, Ian Baring-Gould, Frank A. Oteri, Sean Esterly, Trudy Forsyth, and Ruth Baranowski. 2015a. "Policies to Support Wind Power Development: Key Considerations and Good Practices." *Clean Energy Solutions Center*, May, 2015. https://www.nrel.gov/docs/fy15osti/64177.pdf.

Cox, Sadie, Terri Walters, Sean Esterly, and Sarah Booth. 2015b. "Solar Power: Policy Overview and Good Practices." *Clean Energy Solutions Center*, May, 2015. https://www.nrel.gov/docs/fy15osti/64178.pdf.

Davenport, Coral. 2018. "Major Climate Report Describes a Strong Risk of Crisis as Early as 2040." *The New York Times*, October 7, 2018. https://www.nytimes.com/2018/10/07/climate/ipcc-climate-report-2040.html.

Ernest & Young Global Limited. 2017. "How can oil and gas fuel tomorrow as well as today?" Last modified 2017. https://www.ey.com/us/en/industries/oil---gas/ey-us-perception-of-the-oil-and-gas-industry-2017.

Ewing, Rodney C. 2008. "Nuclear Fuel Cycle: Environmental Impact." *Materials Research Society Bulletin* 33 (April): 338-340. https://www.researchgate.net/publication/231791824_Nuclear_Fuel_Cycle_Environmental_Impact.

Fetter, Steve. 2009. "How long will the world's uranium supplies last?" Scientific American. Last modified 2018. https://www.scientificamerican.com/article/how-long-will-global-uranium-deposits-last/.

Flogas. 2018. "Frequently Asked Questions." Last modified 2018. https://www.flogas.co.uk/frequently-asked-questions/how-long-will-natural-gas-reserves-last.

Friedman, Lisa. 2018. "Trump Administration Formally Rolls Back Rule Aimed at Limiting Methane Pollution." *The New York Times*, September 18, 2018. https://www.nytimes.com/2018/09/18/climate/trump-methane-rollback.html.

Fthenakis, Vasilis, James E. Mason, and Ken Zweibel. 2009. "The Technical, Geographical, and Economic Feasibility for Solar Energy to Supply the Energy Needs of the US." *Energy Policy* 37 (2): 387-399. https://doi.org/10.1016/j.enpol.2008.08.011.

Funk, Cary and Brian Kennedy. 2016. "Public Opinion on Renewables and Other Energy Sources." In *The Politics of Climate*, 52-56. Pew Research Center. October 4, 2016. http://www.pewinternet.org/2016/10/04/public-opinion-on-renewables-and-other-energy-sources/.

Greentech Media. 2015. "How Solar Developers Can Cut the Time and Cost of Installing a Substation." Last modified November 12, 2015. https://www.greentechmedia.com/articles/read/how-solar-developers-can-cut-the-time-and-cost-of-installing-a-substation#gs.iYqZS=Y.

Hamilton, Lawrence C., Erin Bell, Joel Hartter, and Jonathan D. Salerno. 2018. "A change in the wind? US Public Views on Renewable Energy and Climate Compared." *Energy, Sustainability, and Society* 8 (11). https://doi.org/10.1186/s13705-018-0152-5.

Harvey, Chelsea and Niina Heikkinen. 2018. "Congress Says Biomass Is Carbon-Neutral, but Scientists Disagree." *Scientific American E&E News*, March 23, 2018. https://www.scientificamerican.com/article/congress-says-biomass-is-carbon-neutral-but-scientists-disagree/.

Hatch. 2014. "Lifecycle Assessment Literature Review of Nuclear, Wind and Natural Gas Power Generation." Last modified October 9, 2014. https://cna.ca/wp-content/uploads/2014/05/Hatch-CNA-Report-RevE.pdf.

Hausfather, Zeke. 2016. "Is natural gas a bridge fuel?" *Yale Climate Connections*, August 23, 2016. https://www.yaleclimateconnections.org/2016/08/is-natural-gas-a-bridge-fuel/.

Hernandez, R.R., S.B. Easter, M.L. Murphy-Mariscal, F.T. Maestre, M. Tavassoli, E.B. Allen, C.W. Barrows, J. Belnap, R. Ochoa-Hueso, S. Ravi, and M.F. Allen. 2014. "Environmental Impacts of Utility-Scale Solar Energy." *Renewable and Sustainable Energy Reviews* 29: 766-779. https://doi.org/10.1016/j.rser.2013.08.041.

Holt, Mark. 2014. "Nuclear Energy Policy." *Congressional Research Service*, October 15, 2014. https://fas.org/sgp/crs/misc/RL33558.pdf.

Intergovernmental Panel on Climate Change, 2018. "IPCC Press Release: Summary for Policymakers of IPCC Special Report on Global Warming of 1.5ºC Approved by Governments." Last modified October 8, 2018. http://www.ipcc.ch/pdf/session48/pr_181008_P48_spm_en.pdf.

International Panel on Climate Change, n.d. "Special Report: Global Warming of 1.5ºC." Accessed December 4, 2018. https://www.ipcc.ch/sr15/.

Jacquet, Jeffrey B., Anne N. Junod, Dylan Bugden, Grace Wildermuth, Joshua T. Fergen, Kirk Jalbert, Brian Rahm, Paige Hagley, Kathryn J. Braiser, Kai Schafft, Leland Glenna, Timothy Kelsey, Joshua Fershee, David L. Kay, Richard C. Stedman, and James Ladlee. 2018. "A Decade of Marcellus Shale: Impacts to People, Policy, and Culture from 2008 to 2018 in the Greater Mid-Atlantic Region of the United States." *The Extractive Industries and Society* 5 (4): 596-609. https://doi.org/10.1016/j.exis.2018.06.006.

Kennedy, Brian. 2017. "Two-Thirds of Americans Give Priority to Developing Alternative Energy Over Fossil Fuels." *Pew Research Center*, January 23, 2017. http://www.pewresearch.org/fact-tank/2017/01/23/two-thirds-of-americans-give-priority-to-developing-alternative-energy-over-fossil-fuels/.

Kerr, Richard A. 2010. "Natural Gas from Shale Bursts onto the Scene." *Science* 328, (5986): 1624-1626. http://science.sciencemag.org/content/328/5986/1624.

Lazard. 2016. "Growing Percentage of U.S. Voters Favor Increased Commitment to Alternative Energy." Last modified May 18, 2016. https://www.lazard.com/media/2489/2016-alternative-energy-poll-release.pdf.

Lazard. 2017. "Lazard's Levelized Cost of Energy Analysis – Version 11.0." Last modified November 2017. https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf.

Liss, William and Patricia Rowley. 2018. "Assessment of Natural Gas and Electric Distribution Service Reliability." Gas Technology Institute. Last modified July 19, 2018. https://www.gti.energy/wp-content/uploads/2018/11/Assessment-of-Natural-Gas-Electric-Distribution-Service-Reliability-TopicalReport-Jul2018.pdf.

Lofthouse, Jordan, Randy T. Simmons, and Ryan M. Yonk. 2015a. "Reliability of Renewable Energy: Solar." Institute of Political Economy Utah State University. Last modified 2015. https://www.usu.edu/ipe/wp-content/uploads/2015/11/Reliability-Solar-Full-Report.pdf.

Lofthouse, Jordan, Randy T. Simmons, and Ryan M. Yonk. 2015b. "Reliability of Renewable Energy: Wind." Institute of Political Economy Utah State University. Last modified 2015. http://www.usu.edu/ipe/wp-content/uploads/2015/11/Reliability-Wind-Full-Report.pdf.

Loris, Nicolas. 2011. "Natural Gas Policy: Access, Not Over-Regulation and Subsidies." *The Heritage Foundation*, September 21, 2011. https://www.heritage.org/environment/report/natural-gas-policy-access-not-over-regulation-and-subsidies.

Lu, Xi, Michael B. McElroy, and Juha Kiviluoma. 2009. "Global Potential for Wind-Generated Electricity." *Proceedings of the National Academy of Sciences in the United States of America* 106 (27): 10933-10938. http://www.pnas.org/content/pnas/106/27/10933.full.pdf.

Mu, Xiaoyi. 2007. "Weather, Storage, and Natural Gas Price Dynamics: Fundamentals and Volatility." *Energy Economics* 29 (1): 46-63. https://doi.org/10.1016/j.eneco.2006.04.003.

National Academy of Engineering and National Research Council. 2010. "Renewable Energy Policies, Markets, and Deployment in China and the United States." In *The Power of Renewables: Opportunities and Challenges for China and the United States*, 113-149. Washington, DC: The National Academies Press. https://doi.org/10.17226/12987.

National Energy Technology Laboratory. 2014. "Environmental Impacts of Unconventional Natural Gas Development." Last modified 2014. https://www.netl.doe.gov/File%20Library/Research/Oil-Gas/publications/NG_Literature_Review3_Post.pdf.

National Geographic. 2011. "How Much Natural Gas Is There, Really?" Last modified February 16, 2011. https://www.nationalgeographic.com/environment/great-energy-challenge/2011/how-much-natural-gas-is-there-really/.

National Renewable Energy Laboratory. 2011. "NREL Triples Previous Estimates of U.S. Wind Power Potential." Last Modified July 2011. https://www.nrel.gov/docs/fy11osti/51555.pdf.

National Renewable Energy Laboratory. 2018a. "Valuing the Resilience Provided by Solar and Battery Energy Storage Systems." Last modified January 2018. https://www.nrel.gov/docs/fy18osti/70679.pdf.

National Renewable Energy Laboratory. 2018b. "2018 ATB Cost and Performance Study." Annual Technology Baseline. Last modified 2018. https://atb.nrel.gov/electricity/2018/summary.html.

National Renewable Energy Laboratory. n.d.a. "Life Cycle Assessment Harmonization." Accessed November 29, 2018. https://www.nrel.gov/analysis/life-cycle-assessment.html.

National Renewable Energy Laboratory. n.d.b. "Wind Power Reliability Research." Accessed December 1, 2018. https://www.nrel.gov/wind/reliability.html.

National Research Council. 2007. "Ecological Effects of Wind Energy Development." In *Environmental Impacts of Wind-Energy Projects*, 67-139. Washington, DC: The National Academies Press. https://doi.org/10.17226/11935.

Natural Resources Defense Council. 2017. "Powering into the Future: Renewable Energy, Reliability, and Reshaping the Grid." Last modified August 2017. https://www.nrdc.org/sites/default/files/powering-future-grid-reliability-fs.pdf.

Nordhaus, Ted and Jessica Lovering. 2016. "Does Climate Policy Matter? Evaluating the Efficacy of Emissions Caps and Targets around the World." *The Breakthrough*, November 28, 2016. http://thebreakthrough.org/issues/Climate-Policy/does-climate-policy-matter.

North American Electric Reliability Corporation. 2017. "Special Reliability Assessment: Potential Bulk Power System Impacts Due to Severe Disruptions on the Natural Gas System." Last modified August 31, 2018. https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_SPOD_11142017_Final.pdf.

Nuclear Energy Institute. 2018. "U.S. Nuclear Generating Statistics." Last modified April 2018. https://www.nei.org/resources/statistics/us-nuclear-generating-statistics.

Nuclear Energy Institute. n.d. "The Advantages of Nuclear Energy." Accessed December 1, 2018. https://www.nei.org/advantages.

Nunez, Christina. 2014. "How Green Are Those Solar Panels, Really?" *National Geographic*, November 11, 2014. https://news.nationalgeographic.com/news/energy/2014/11/141111-solar-panel-manufacturing-sustainability-ranking/.

Olson-Hazboun, Shawn K. 2017. "Public Opinion on Renewable Energy: The Nexus of Climate, Politics, and Economy." PhD diss., Utah State University. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=6924&context=etd.

Orvis, Robbie, Andrew Goggins, Brendan Pierpont, Maren Wenzel, Laura Sanchez, and David Posner. 2017. "The Department of Energy's Grid Reliance Pricing Protocol: A Cost Analysis." Energy Innovation Policy & Technology LLC. Last modified October, 2017. https://energyinnovation.org/wp-content/uploads/2017/12/20171025_Resilience-NOPR-Cost-Research-Note-UPDATED.pdf.

Page, Carly. 2017. "How Reliable Is Natural Gas? An Historical Overview of Natural Gas Transmission's Outage Track Record." Public Utilities Commission of Nevada. Last modified 2017. http://www.usaee.org/usaee2017/submissions/OnlineProceedings/Natural%20Gas%20Reliability%20paper%20CJP%20Final.pdf.

Panfil, Michael. 2014. "Resiliency+: Renewable Energy Can Boost Grid Resilience in Vulnerable New Jersey." *Environmental Defense Fund*, April 30, 2014. http://blogs.edf.org/energyexchange/2014/04/30/resiliency-renewable-energy-can-boost-grid-resilience-in-vulnerable-new-jersey/.

Parkes Solar Farm. 2015. "FAQs." Last modified 2015. https://parkessolarfarm.com.au/faqs/.

Pfaffel, Sebastian, Stefan Faulstich, and Kurt Rohrig. 2017. "Performance and Reliability of Wind Turbines: A Review." *Energies* 10 (11): 1904. https://doi.org/10.3390/en10111904.

Pierce Jr., Richard J. 2012. "Natural Gas: A Long Bridge to a Promising Destination." *Utah Environmental Law Review* 32 (2): 245-252. http://epubs.utah.edu/index.php/jlrel/article/view/787.

Pinar Pérez, Jesús María, Fausto Pedro García Márquez, Andrew Tobias, and Mayorkinos Papaelias. 2013. "Wind Turbine Reliability Analysis." *Renewable and Sustainable Energy Reviews*, 23: 463-472. https://doi.org/10.1016/j.rser.2013.03.018.

Plumer, Brad. 2013. "These Maps Show the Best Places to Put Solar and Wind Power. (It's not where you think.)" *The Washington Post*, July 15, 2013. https://www.washingtonpost.com/news/wonk/wp/2013/07/15/these-maps-show-the-best-places-to-put-solar-and-wind-power-its-not-where-you-think/?noredirect=on&utm_term=.73c216f0307b.

Price, R. and J.R. Blaise. 2002. "Nuclear Fuel Resources: Enough to Last?" NEA Updates, NEA News, No. 20.2. Last modified 2002. https://www.oecd-nea.org/nea-news/2002/20-2-Nuclear_fuel_resources.pdf.

Rapier, Robert. 2018. "Natural Gas Is Already A Bridge Fuel." *Forbes*, September 2, 2018. https://www.forbes.com/sites/rrapier/2018/09/02/natural-gas-is-already-a-bridge-fuel/#4df75e53975f.

Rashad, S.M. and F.H. Hammad. 2000. "Nuclear Power and the Environment: Comparative Assessment of Environmental and Health Impacts of Electricity-Generating Systems." *Applied Energy* 65: 211-229. https://pdfs.semanticscholar.org/46c2/cf9f80b0ba08d50ea65fbb8b9aaae2ddb665.pdf.

Rollins, Myron, Jacob Tutmaher, and Ted Pintcke. 2012. "Combined Cycle – Is it time to build?" Black & Veatch Holding Company. Last modified 2012. https://www.bv.com/docs/reports-studies/combined-cycles-is-it-time-to-build.pdf.

Rosa, Eugene A. and Riley E. Dunlap. 1994. "Poll Trends: Nuclear Power: Three Decades of Public Opinion." *The Public Opinion Quarterly* 58 (2): 295-324. https://www.jstor.org/stable/2749543?seq=1#page_scan_tab_contents.

Safer, Don and Sara Barczak. 2015. "Watts Bar Unit 2, Last Old Reactor of the 20th Century: A Cautionary Tale." *Bulletin of the Atomic Scientists*, October 8, 2015. https://thebulletin.org/2015/10/watts-bar-unit-2-last-old-reactor-of-the-20th-century-a-cautionary-tale/.

Saidur, R., N.A.Rahim, M.R. Islam, and K.H. Solangi. 2011. "Environmental Impact of Wind Energy." *Renewable and Sustainable Energy Reviews* 15 (5): 2423-2430. https://doi.org/10.1016/j.rser.2011.02.024.

Shaftel, Holly. 2018. "Scientific Consensus: Earth's Climate is Warming." NASA Global Climate Change Vital Signs of the Planet. Last modified November 15, 2018. https://climate.nasa.gov/scientific-consensus/.

Shaner, Matthew R., Steven J. Davis, Nathan S. Lewis, and Ken Caldeira. 2018. "Geophysical Constraints on the Reliability of Solar and Wind power in the United States." *Energy & Environmental Science* 4: 914-925. https://pubs.rsc.org/en/content/articlelanding/2018/ee/c7ee03029k#!divAbstract.

Sisk, Amy. 2017. "The Rise of Wind Energy Raises Questions About Its Reliability." *National Public Radio*, June 22, 2017. https://www.npr.org/2017/06/22/532763718/the-rise-of-wind-energy-raises-questions-about-its-reliability.

Smead, Richard G. 2010. "Price Instability in the U.S. Natural Gas Industry Historical Perspective and Overview." Last modified July 15, 2010. https://bipartisanpolicy.org/wp-content/uploads/sites/default/files/Introduction%20to%20North%20American%20Natural%20Gas%20Markets_0.pdf.

Sovacool, Benjamin K. 2009. "The Intermittency of Wind, Solar, and Renewable Electricity Generators: Technical Barrier or Rhetorical Exercise?" *Utilities Policy* 17 (3-4): 288-296. https://doi.org/10.1016/j.jup.2008.07.001.

Stein, Devin, Michael E. Reed, Saige Bowen, Chet D. Garlick, Ryan Lee, Richard W. Poll, and Madi Smith. 2017. "U.S. Nuclear Power: Regulatory Barriers and Energy Potential." Strata. Last modified August 2017. https://strata.org/pdf/2017/us-nuclear-power.pdf.

Steinhauser, Georg, Alexander Brandl, and Thomas E. Johnson. 2014. "Comparison of the Chernobyl and Fukushima Nuclear Accidents: A Review of the Environmental Impacts." *Science of the Total Environment* 470-471: 800-817. https://doi.org/10.1016/j.scitotenv.2013.10.029.

Tabuchi, Hiroko. 2017. "Coal Mining Jobs Trump Would Bring Back No Longer Exist." *The New York Times*, March 29, 2017. https://www.nytimes.com/2017/03/29/business/coal-jobs-trump-appalachia.html.

Thomas, Merryn, Nicholas Pidgeon, Darrick Evensen, Tristan Partridge, Ariel Hasell, Catherine Enders, Barbara Herr Harthorn, and Michael Bradshaw. 2017. "Public Perceptions of Hydraulic Fracturing for Shale gas and Oil in the United States and Canada." *Wires Climate Change* 8 (3). https://doi.org/10.1002/wcc.450.

Tiemann, Mary and Adam Vann. 2015. "Hydraulic Fracturing and Safe Drinking Water Act Regulatory Issues." *Congressional Research Service*, July 13, 2015. https://fas.org/sgp/crs/misc/R41760.pdf.

Trabish, Herman K. 2017. "Is renewable energy threatening power reliability?" *Utility Dive*, June 1, 2017. https://www.utilitydive.com/news/is-renewable-energy-threatening-power-reliability/443701/.

Union of Concerns Scientists. 2013a. "Environmental Impacts of Solar Power." Last modified March 5, 2013. https://www.ucsusa.org/clean-energy/renewable-energy/environmental-impacts-wind-power#.XAMD0GhKhPZ.

Union of Concerns Scientists. 2013b. "Environmental Impacts of Wind Power." Last modified March 5, 2013. https://www.ucsusa.org/clean-energy/renewable-energy/environmental-impacts-wind-power#.XAMD0GhKhPZ.

Union of Concern Scientists. 2015. "Is Renewable Energy Reliable?" Last modified April 23, 2015. https://www.ucsusa.org/clean-energy/increase-renewable-energy/fact-renewable-energy-is-reliable#.XAMNx2hKhPZ.

Union of Concerned Scientists. n.d. "Environmental Impacts of Natural Gas." Accessed November 30, 2018. https://www.ucsusa.org/clean-energy/coal-and-other-fossil-fuels/environmental-impacts-of-natural-gas#.XAG8o5xKjIV.

U.S. Department of Energy. 2015a. "Levelized Cost of Energy (LCOE)." Office of Indian Energy. Last modified 2015. https://www.energy.gov/sites/prod/files/2015/08/f25/LCOE.pdf.

U.S. Department of Energy. 2015b. "Unlocking Our Nation's Wind Potential." Office of Energy Efficiency & Renewable Energy. Last modified May 19, 2015. https://www.energy.gov/eere/articles/unlocking-our-nation-s-wind-potential.

U.S. Department of Energy. n.d.a. "Environmental Impacts and Siting of Wind Projects." Accessed December 1, 2018. https://www.energy.gov/eere/wind/environmental-impacts-and-siting-wind-projects.

U.S. Department of Energy. n.d.b. "Reliability and Safety." Accessed December 1, 2018. https://www.energy.gov/eere/solar/reliability-and-safety.

U.S. Department of Energy. n.d.c. "Solar Energy in the United States." Accessed November 30, 2018. https://www.energy.gov/eere/solarpoweringamerica/solar-energy-united-states.

U.S. Energy Information Administration. 2017a. "Natural Gas Weekly Update for the Week Ending September 27, 2017." Last modified November 21, 2017. https://www.eia.gov/naturalgas/weekly/archivenew_ngwu/2017/09_28/.

U.S. Energy Information Administration. 2017b. "Wind Turbine Heights and Capacities Have Increased Over the Past Decade." Today in Energy. Last modified November 29, 2017. https://www.eia.gov/todayinenergy/detail.php?id=33912.

U.S. Energy Information Administration. 2018a. "Almost All Power Plants That Retired in the Past decade Were Powered by Fossil Fuels." Last modified January 9, 2018. https://www.eia.gov/todayinenergy/detail.php?id=34452.

U.S. Energy Information Administration. 2018b. "Direct Federal Financial Interventions and Subsidies in Energy in Fiscal Year 2016." Last modified April 24, 2018. https://www.eia.gov/analysis/requests/subsidy/.

U.S. Energy Information Administration. 2018c. "Electricity Market Module." Last modified April 2018. https://www.eia.gov/outlooks/aeo/assumptions/pdf/electricity.pdf.

U.S. Energy Information Administration. 2018d. "How much natural gas does the United States have, and how long will it last?" Last modified April 9, 2018. https://www.eia.gov/tools/faqs/faq.php?id=58&t=8.

U.S. Energy Information Administration. 2018e. "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2018." Last modified March 2018. https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf.

U.S. Energy Information Administration. 2018f. "Natural Gas and the Environment." Last modified August 22, 2018. https://www.eia.gov/energyexplained/index.php?page=natural_gas_environment.

U.S. Energy Information Administration. 2018g. "Nuclear Power and the Environment." Last modified April 30, 2018. https://www.eia.gov/energyexplained/index.php?page=nuclear_environment.

U.S. Energy Information Administration. 2018h. "Solar Energy and the Environment." Last modified August 31, 2018. https://www.eia.gov/energyexplained/?page=solar_environment.

U.S. Energy Information Administration. n.d. "What is Price Volatility?" Accessed December 1, 2018. https://www.eia.gov/naturalgas/weekly/archivenew_ngwu/2003/10_23/Volatility%2010-22-03.htm.

U.S. Environmental Protection Agency. 2018. "Sources of Greenhouse Gas Emissions." Last modified October 9, 2018. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

U.S. Global Change Research Program. 2018. "Fourth National Climate Assessment." Last modified 2018. https://nca2018.globalchange.gov/chapter/1/.

U.S. Nuclear Regulatory Commission. 2015. "Reactor License Renewal Overview." Last modified March 9, 2015. https://www.nrc.gov/reactors/operating/licensing/renewal/overview.html.

U.S. Nuclear Regulatory Commission. 2018a. "Combined License Applications for New Reactors." Last modified April 25, 2018. https://www.nrc.gov/reactors/new-reactors/col.html.

U.S. Nuclear Regulatory Commission. 2018b. "NRC Datasets." Last modified August 17, 2018. https://www.nrc.gov/reading-rm/doc-collections/datasets/.

Walton, Robert. 2018. "Despite Renewables Gains, Gas Leads New US Generation." *Utility Dive*, July 8, 2018. https://www.utilitydive.com/news/fossil-fuels-dominate-energy-infrastructure-gas-consumption-up-24-since/527239/.

Wang, Qiang, Xi Chen, Awadhesh N. Jha, and Howard Rogers. 2014. "Natural Gas from Shale Formation – The Evolution, Evidences and Challenges of Shale Gas Revolution in the united States." *Renewable and Sustainable Energy Reviews* 30: 1-28. https://doi.org/10.1016/j.rser.2013.08.065.

Wang, Zhongmin and Krupnick, Alan. 2013. "A Retrospective Review of Shale Gas Development in the United States: What Led to the Boom?" *Resources for the Future*, April 2013: 32. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-13-12.pdf.

Weisser, Daniel. 2007. "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies." *Energy* 32 (9): 1543-1559. https://doi.org/10.1016/j.energy.2007.01.008.

Wood Mackenzie. 2015. "A Comparison of US Oil and Natural Gas Policies: Pro-Development Policies vs. Proposed Regulatory Constraints." Last modified June 22, 2015. https://www.api.org/~/media/Files/Policy/Jobs/Wood-Mackenzie-Report-2015.pdf.

World Nuclear Association. 2011. "Comparison Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources." Last modified July 2011. http://www.world-nuclear.org/uploadedFiles/org/WNA/Publications/Working_Group_Reports/comparison_of_lifecycle.pdf.

World Nuclear Association. 2013. "Environment and Health in Electricity Generation." Last modified November 2013. http://www.world-nuclear.org/information-library/energy-and-the-environment/environment-and-health-in-electricity-generation.aspx.

World Nuclear Association. 2018a. "Advanced Nuclear Power Reactors." Last modified October 2018. http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/advanced-nuclear-power-reactors.aspx.

World Nuclear Association. 2018b. "Supply of Uranium." Last modified August 2018. http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/supply-of-uranium.aspx.